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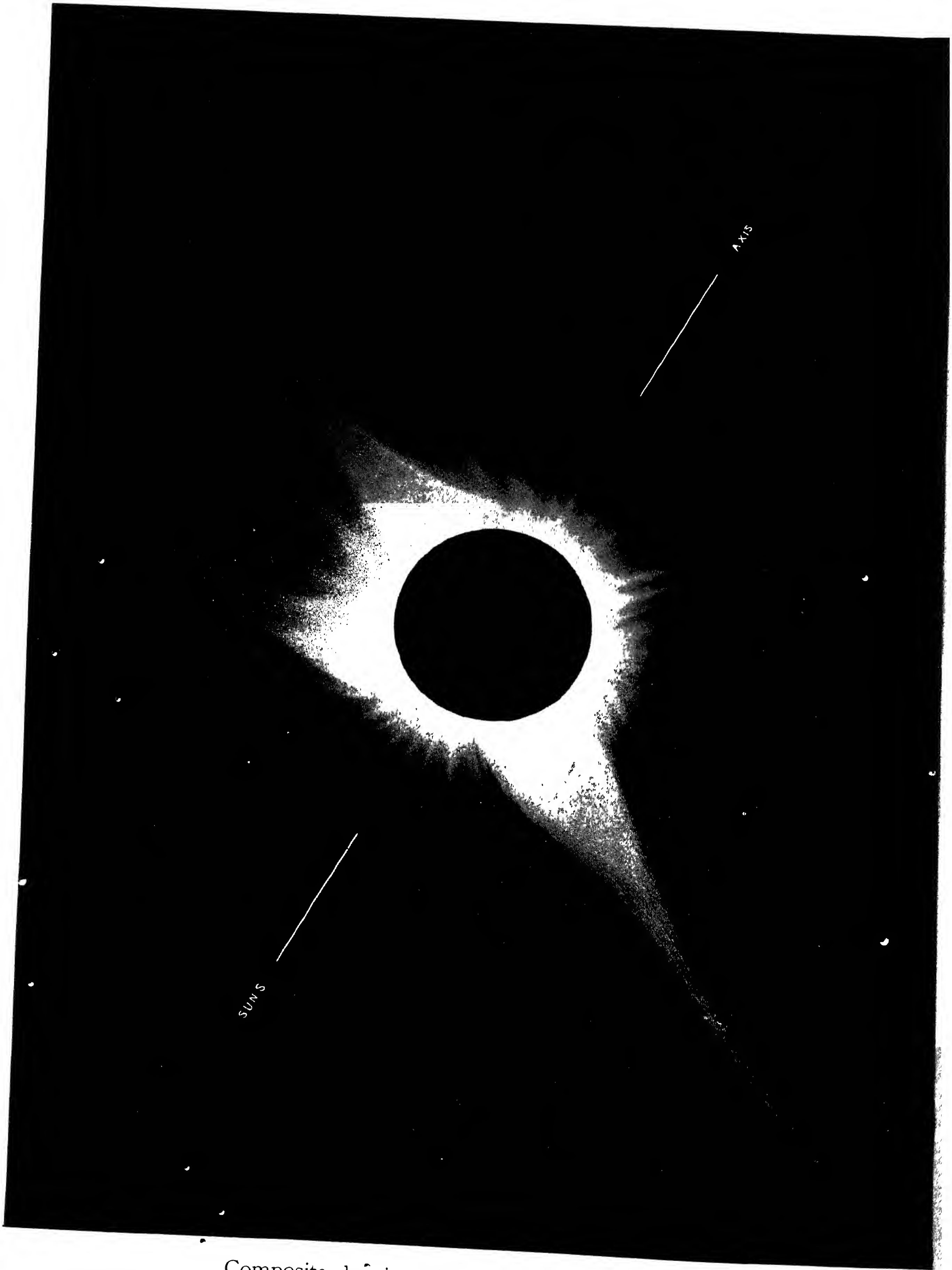


Composite drawing of the corona from photographs.

Publications of the Maharaja Takhtasingji Observatory, Poona.—Vol. I.

# REPORT

ON THE

# TOTAL SOLAR ECLIPSE

OF

## JANUARY 21-22, 1898,

## AS OBSERVED AT JEUR IN WESTERN INDIA.

BY

KAVASJI DADABHAI NAEGAMVALA,

M.A., F.R.A.S., Etc.,

Director of the Observatory.

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1902.

# PREFATORY REMARKS.

Some explanation is necessary regarding the delay in publishing the report of the Eclipse. Though Mr. W. Shackleton had secured the first record of the "flash" at Novaya Zemyla in 1896, the spectrum of this important solar phenomenon was for the first time adequately obtained at the Indian Eclipse of 1898, and it was at once evident that a proper appreciation of this important record could only be gained by comparing it with stellar spectra of solar and other related types. For the last two years I have been, therefore, engaged in securing stellar spectra, but the progress of the work, which is still in hand, has been much hampered owing to certain mechanical defects in the prismatic camera.

I have therefore considered it advisable to place before the astronomical world the accompanying account of my operations at Jeur without further delay and it is hoped that it will prove acceptable.

My special thanks are due to Mr. Henry Cousens, Superintendent of the Archæological Survey for Western India, for the great skill with which he has kindly prepared for this report the drawings of the corona and of the spectra taken with the ultra-violet prismatic camera and the slit spectroscope.

K. D. NAEGAMVALA.

*Maharaja Takhtasingji Observatory,*
*Poona, November 1, 1901.*

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# THE TOTAL SOLAR ECLIPSE OF JANUARY 21-22, 1898, AS OBSERVED AT JEUR, INDIA.

## CHAPTER I.

### Preliminary Preparations.

#### *I.—Preparations for observing the Eclipse.*

On the 23rd of February 1896, I addressed the Government of Bombay through the Principal of the College of Science, Poona, drawing the attention of Government to the necessity of preparing in time for observing the Total Eclipse of the Sun of January 21-22, 1898.

The instruments of the Observatory were not such as could be advantageously employed for this particular purpose and I estimated the probable expenditure on the requisite instruments at Rs. 10,000, half of which I proposed to collect by private subscriptions. At the same time I offered to proceed to Norway to take part in observing the Total Eclipse of August 9, 1896, in order to familiarise myself, by actual experience, with the most recent and approved methods of attacking the various eclipse problems.

Government were pleased to accord their sanction to my proposals by their Resolution in the Educational Department, No. 951, dated 21st May 1896. The amount of Rs. 5,000 that I had undertaken to collect was speedily subscribed by some of the Princes of the Bombay Presidency and private individuals, to whose enlightened liberality I beg to take this opportunity of expressing my sincere obligations. The Right Honourable the Secretary of State for India was also communicated with by Government and permission was kindly obtained by His Lordship for my accompanying the Royal and the Royal Astronomical Societies' Joint Expedition to Vadsö in Finland under the leadership of Doctor A. A. Common, President of the Royal Astronomical Society.

As is well known, the expedition failed owing to the cloudy state of the weather, nevertheless I had the unique opportunity of examining the numerous instruments brought together on that occasion by five different parties of European astronomers.

On the return of the expedition to England arrangements were entered into for the purchase of the requisite instruments, the most important of which was a six-inch Cooke triplet equatorial refractor with a 45° prism and a cœlostat of 12″ diameter; the latter being a special loan from the Chief of Miraj (Senior), whose enlightened encouragement of science is well known in the Deccan.

I was, however, strongly urged by Sir Norman Lockyer to add, if possible, one more prism to the Cooke prismatic camera, in order to obtain twice the dispersion ever attempted before, and on my return to India in November 1896 I again approached Government on the subject and offered to collect a supplementary sum of Rs. 3,000

if Government would consent to increase their grant by Rs. 2,000 for the purchase of the second prism and some other accessories. Government were pleased once more to accede to my request and some of my friends once more came to my help by subscribing the three thousand rupees I had undertaken to collect. However, through various reasons the supplementary orders were not put in the hands of the opticians till the middle of the year 1897. The result of this unavoidable delay was that most of the instruments arrived just in time for the eclipse, some of them reaching the camp within the last ten or fifteen days. I regret this extremely, as an extra fortnight, or even a week, would have enabled me to attain much greater precision in the various adjustments, and the results would have been far superior to what it was my fortune to obtain.

## *II.—Selection of a Site.*

The choice of a station was naturally limited within the belt of totality crossed by the Great Indian Peninsula and the Southern Maratha Railway lines to the south of Poona. On the former the central line passed near the station of Jeur in the Sholápur District, and on the latter near the station of Karád in the district of Sátára.

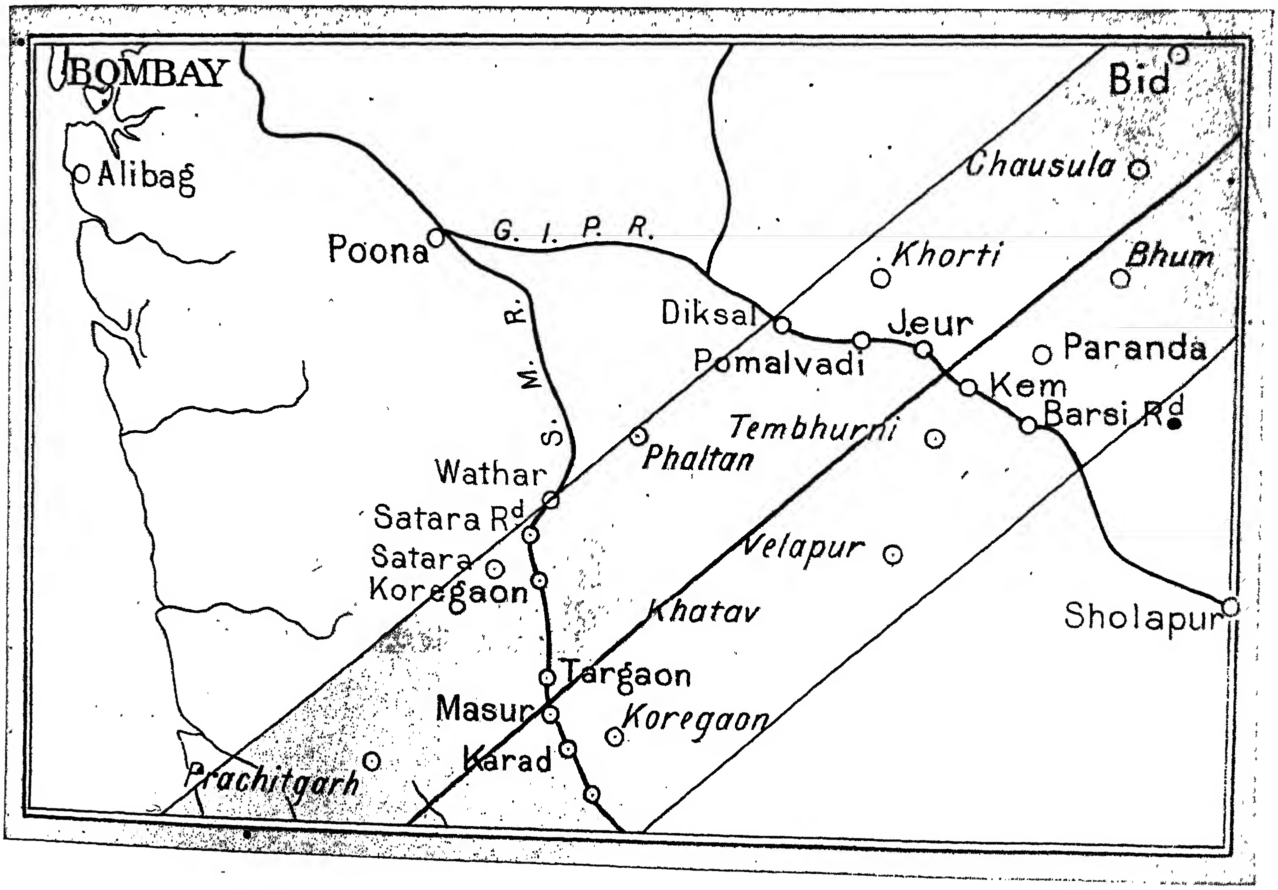


*Fig. 1 : Path of totality through the Deccan.*

The locality on the Southern Maratha line was superior to that on the other: it was hilly, affording many points of vantage, was well supplied with water, and was less liable to be affected by clouds drifted across by the north-east monsoon; but plague was raging terribly near Karád, and the idea of locating the camp there had to be abandoned. The country in the vicinity of Jeur was, on the other hand, flat, almost devoid of trees except a few scraggy *bábuls* (*Acacia arabica*), and the supply of water was not plentiful. Plague had also appeared in Karmálá, the chief town of the *táluká* (sub-district), but had not yet spread to the surrounding villages. A spot four miles from the Jeur railway station on the road leading to the village of Wángi and a little over a mile east of the central line was finally selected near a fair supply of well water. The exact location of the camp is shown in Plate I.

On the 7th December 1897, Professor W. W. Campbell, the delegate of the Lick Observatory, arrived in Bombay, and I visited the camping ground with him on the 10th idem. He had the first choice of a site for his camp and I fixed upon a spot about one hundred yards further to the west for my observing camp. The instruments and the necessary paraphernalia of a camp were despatched to Jeur on the 14th of December 1897. The Japanese astronomers, Professors Tirao and Hiramaya, with their assistants, soon followed and they were assigned sites for instruments and camp still further west. Professor Burckhalter from the Chabot Observatory, California, U. S. A., arrived at the same time and he selected a site for his telescope two miles further south, near the village of Wángi (see Plate I).

Dr. A. W. Thomson, D.Sc., Professor of Engineering in the College of Science, who had kindly consented to help me in the general management of the camp, arrived a week afterwards, and I very soon found the administrative work of looking after the numerous requirements of the various parties in addition to my own special work so very exacting that I had to request him to take over from me this portion of my duty. He very generously and readily acquiesced in my proposal and my most sincere thanks are due to him, not only for this, but for the exceptionally valuable help he rendered me throughout the operations.

Assistant Surgeon P. P. Mulla, of the Bombay Civil Medical Establishment, was deputed by Government to be in charge of the sanitary arrangements of the camp. Dr. Mulla was good enough to volunteer his help to me and he rendered me much valuable service, particularly by assisting me at night in adjusting the various telescopes. He also kindly undertook the duties of time-caller on the day of the eclipse.

Mr. K. R. Godbole, M.C.E., Executive Engineer of the District, under instructions of Government, placed the resources of his department at the disposal of the astronomers, and the work of building up pillars, erecting huts, &c., was done expeditiously and satisfactorily by the assistant specially deputed for the purpose.

Mr. T. J. B. Thatcher, District Superintendent of Police, afforded all necessary help for guarding the camp and in particular in drawing a cordon at the Jeur station on the day of the eclipse, which effectually prevented crowds of sight-seers

and on-lookers disturbing the operators during the important two minutes of observation. He also very kindly placed at my disposal a large number of watchman's lanterns for use during the eclipse.

The important duty of providing manual labour, arranging for market supplies, &c., devolved upon Ráo Sáheb D. D. Pátankar, Mámlatdár of Karmálá, who was indefatigable in his exertions to meet all our wants. To all these officers thanks are due for the zeal and readiness with which they met our multifarious demands and requirements.

The Honourable Mr. E. Giles, M.A., Director of Public Instruction, who was entrusted by Government with the general charge of supervising eclipse arrangements throughout the Presidency, arrived in camp the day before the eclipse and remained there till the day following.

The location of the camp together with those of the American and Japanese astronomers is given in Plate II.

### *III.—Conditions of the Eclipse at Jeur.*

The conditions of totality for the eclipse in the neighbourhood of Jeur for Lat. 18° 12′ N. and Long. 75° 12′ E. were as follows :—

| | |
|---|---|
| Beginning of totality ... ... ... | 1 h. 19 m. 36 s. M. M. T. |
| End of totality ... ... ... | 1 h. 21 m. 35 s. M. M. T. |
| Zenith distance ... ... ... | 40°. |
| Position angle of second contact in the direction N. to E. from the vertex ... ... | 46°. |
| Position angle of third contact ... ... | 210°. |
| Movement of the Moon per second ... ... | 0″·38. |

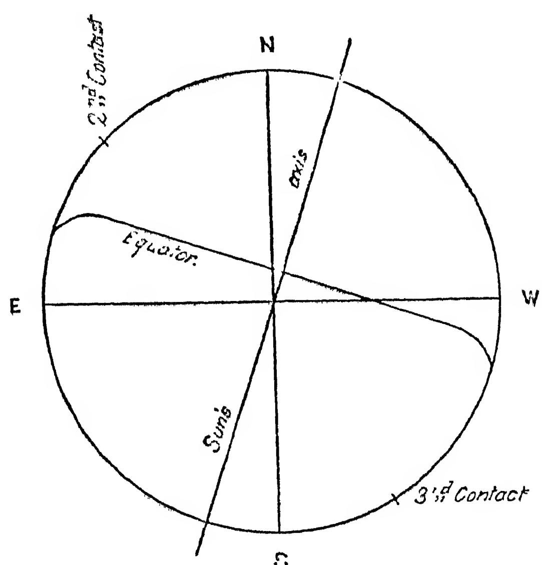


*Fig. 2 : Conditions of totality at Jeur.*

As it was finally determined to use the large prismatic camera as an equatorial, the question of the inclination of the chromospheric arcs to the length of the spectrum with the dispersion of the prisms north and south had to be considered. Had the second contact taken place at the vertex of the sun the arcs would have come out symmetrically arranged at right angles to the dispersion, and the middle point of each arc would have been tangential to the Fraunhofer lines in the spectrum of a star taken with the same instrument. In the accompanying figure

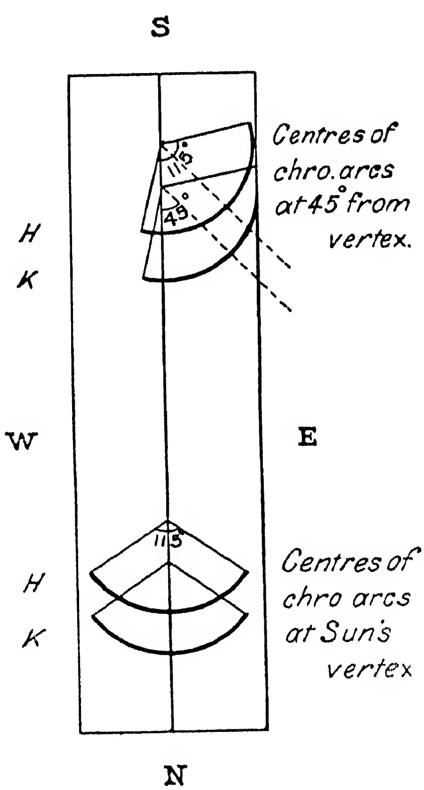


*Fig. 3 ; Position of chromospheric arcs in the prismatic spectrum.*

I have shown how arcs of 115° of H and K would have been then situated. For constructing the diagram I have taken the actual breadth of the spectrum of the solar disc that the prismatic camera was calculated to give, and the distance between the middle points of the arcs is also the same as that between the Fraunhofer lines H and K that the instrument was capable of giving. As the second contact was, however, to occur at nearly 45° to the east from the vertex, it will be seen from the diagram that for the same arcs of 115°, though the eastern edges almost touch one another, the other extremities of the arcs are well apart. The prisms of the six-inch camera were, therefore, allowed to remain in the stellar position, as this could be done

without sacrificing any accuracy in the results and as it, at the same time, enabled me to adjust for focus by means of star spectra.

### *IV.—Programme of Work.*

The instruments available were :

(1) a 6″ triple achromatic with two objective prisms of 45° each,
(2) the equatorial stand for above,
(3) a 12″ cœlostat,
(4) a 12″ siderostat,
(5) an 8″ achromatic lens,
(6) a 6″ achromatic lens,
(7) a set of small spar prisms and lenses,
(8) a number of photographic doublets of 4″ aperture and downwards,
(9) a 3″ spectroscope,
(10) a 3″ equatorial with spectroscope attached,
(11) a 3″ equatorial refractor,
(12) a binocular spectroscope,
(13) a three-prism table spectroscope, and
(14) various meteorological instruments.

From the first I had proposed to concentrate the powers of the expedition in the spectroscopic line, assigning a secondary place only to the subjects of photographing the corona and of eye-observations. I had, moreover, intended to employ the 6″ prismatic camera with the cœlostat, and to use the siderostat with the slit and ultra-violet spectroscopes. A series of photographic lenses, together with the 6″ achromatic, I had proposed to mount equatorially on the stand of the triple achromatic. But the very late arrival of the instruments compelled me reluctantly to change my plans, and the programme finally adopted was as follows :—

(1) 6″ prismatic camera on equatorial stand for the spectra of the "flash" and corona.

(2) 12″ Foucault siderostat with—

(*a*) Three-inch slit spectroscope,
(*b*) Two-prism quartz-calcite camera, and
(*c*) One-prism quartz-calcite camera.

(3) 12″ cœlostat with 6″ achromatic lens, as coronograph.
(4) 4″ portrait lens as coronograph.
(5) An integrating spectrograph.
(6) An analysing slitless spectroscope.
(7) A telescope for search of the white prominences of Tacchini.

(8) An objective prism telescope.
(9) Sketches of the corona.
(10) Meteorological observations.
(11) Shadow bands.
(12) Visibility of the corona out of totality.
(13) Visibility of stars and planets.
(14) Effect on plants and animals and aspect of the landscape.

*Personnel.*

*Director*—Professor K. D. Naegamvala with Mr. Kulkarni as recorder and Mr. Paranjpe as time-keeper, for signaling the contacts and for spectroscopic eye-observations with instrument No. 12.

*Time signals*—Dr. Mulla and Mr. Kanitkar.

*Seconds call*—Messrs. Pitre and Barve.

No. 1.—*Six-inch prismatic camera.*

Dr. A. W. Thomson, assisted by Mrs. Thomson and Messrs. Bana, Gonsalves, Vachha, Vakil and Vaz (students, College of Science).

No. 2 (*a*).—*Three-inch slit spectroscope.*

Mr. H. J. Unvala, B.Sc., assisted by Messrs. Sanga and Wadia, students.

No. 2 (*b*).—*Two-prism quartz-calcite camera.*

Professor G. M. Woodrow assisted by Messrs. Dani and Vaidya, students.

No. 2 (*c*).—*One-prism quartz-calcite camera.*

Mr. S. D. Writer assisted by Messrs. Dubash and Mistri, students.

No. 3.—*Six-inch coronograph.*

Mr. A. G. Hudson assisted by Mr. DeSouza, student.

No. 4.—*Four-inch coronograph.*

Mr. D. D. Kapadia, M.A., B.Sc., assisted by Mr. J. Nazareth, student.

No. 5.—*Integrating spectroscope.*

Mr. D. D. Sanga assisted by Messrs. Bharucha and Lilamvala, students

No. 6.—*Analysing slitless spectroscope.*

Rev. Father F. X. Haan, S.J., assisted by Mr. M. Vakil, B.A.

No. 7.—*Search for white prominences.*

Mr. G. B. Rishi, L.C.E.

No. 8.—*Objective-prism telescope.*

Rev. Dr. D. Mackichan assisted by Mr. Shevde, student.

No. 9.—*Sketches of the corona.*

Principal H. F. Beale and Messrs. Kadne and Yadav.

No. 10.—*Meteorological observations.*

Messrs. Banarji, Bal, Gosh and Senroy.

No. 11.—*Shadow bands.*

Messrs. Godbole, Joshi and Sataravala.

No. 12.—*Visibility of the corona outside totality.*

Messrs. Murzban and P. Naegamvala.

No. 13.—*Visibility of stars and planets.*

Professor R. N. Apte, M.A., LL.B.

No. 14.—*Effects on plants and animals.*

Messrs. Pavri and R. D. Naegamvala.

## *V.—Disposition of the Observing Camp.*

The camp was laid out in the form of a rectangle. In the north-east corner was the 6″ prismatic camera, next to it along the north side of the rectangle was the 12″ siderostat with the slit spectroscope and the two ultra-violet spectroscopes, then came the six-inch coronograph. Between the siderostat and the six-inch coronograph, a little further to the north, was located the seconds-clock and behind it still north was the four-inch coronograph. The west side of the rectangle was occupied by the meteorological hut; on the south side commencing from the west was the slitless analysing spectroscope, then the three-inch visual telescope, next to it was the objective-prism telescope, followed by the integrating spectrograph; then out of the line, a little further south, was the photographic dark room, and finally to the east in a line with the six-inch prismatic camera was the seat of the Director. The time-signallers occupied a position in the centre of the rectangle. The workshop was a little further away to the south-east of the rectangle.

As it was found for several days before the eclipse that a pretty stiff breeze blew from the east just at midday near the time of the eclipse, a high sail-cloth screen was erected to break the strength of the wind and on its upright posts the occulting discs for drawing the corona were erected (see Plates VI and VII). In Plate III the camp is shown as laid out and the ground-plan of the same is given in Plate IV. Plates V and VI represent the full staff of observers.

## *VI.—Final preparations.*

The College professors and students and most of the others who had volunteered their help were in camp five days before the eclipse. Frequent drills were held for

the next four days and the precision with which the operations were gone through left nothing to be desired. My thanks are due to them all for their valuable help.

The calls previous to totality were as follows :—

| | | | | |
|---|---|---|---|---|
| 30 | minutes | before | totality | —" To posts." |
| 25 | ,, | ,, | ,, | " Bring out coronograph slides." |
| 20 | ,, | ,, | ,, | " Wind up siderostat clock." |
| 15 | ,, | ,, | ,, | " Wind up cœlostat clock and centre the sun." |
| 14 | ,, | ,, | ,, | " Bring out photographic slides and light lamps." |
| 12 | ,, | ,, | ,, | " Re-wind equatorial clock." |
| 5 | ,, | ,, | ,, | " Attention." |

Then each passing minute was called out from "four" to "one"; an expectant halt and then the call went forth from me of "*Flash*," soon followed by that of "*Totality*." From that till the end of totality the time-callers gave out every tenth second in the reverse order, "120 seconds," "110 seconds" and so forth up to zero. During each interval of ten seconds the individual seconds were rung out on an empty kerosine oil can with the help of a simple seconds pendulum; this enabled each operator to count and record his individual exposure.

In carrying out the general operations the operators showed a remarkable degree of precision, though here and there it was afterwards ascertained that some mistakes, unavoidable under the peculiar circumstances, were made by a few of them.

## CHAPTER II.

### Eclipse Observations.

### *VII.—The Six-inch Prismatic Camera.*

The optical parts of the instrument employed consist of a six-inch triple achromatic lens by Cooke of 93·6 inches focus and two prisms 45° each with faces 8″×6″. The deviation of the combined train of prisms is 65° for the $H_\gamma$ region and the length of the visible spectrum from D to K is nearly 6·5 inches. The chromospheric rings are nearly 0·95 inch in diameter.

The tube carrying the optical parts is of T-iron lattice-work, 12″×12″ square, and covered with thin sheet steel rivetted on to the T-iron frame-work; the tube is thus exceedingly firm and rigid. The lens is mounted inside the tube and the prisms are carried independently of the lens and its mounting on a flange on the outer end of the tube. At the other end of the tube is a wooden camera with slides described below.

The stand carrying the optical tube is a very massive one, such as is usually supplied with Cooke's standard eight-inch refractors, and is furnished with all necessary means for adjustment. The height of the instrument, when mounted and ready for observation, was 13 feet from the ground. The clock-work is supplied with a Russell electric control, but this was not used during the eclipse.

The instrument arrived only ten days before the eclipse and much trouble was experienced in removing the pillar of the stand from the railway station at Jeur and bringing it into camp four miles away. A deep *nálá* (watercourse) had to be crossed on the way and at first it was felt that the local hauling facilities were not equal to the task. The question of locating this instrument, the most important of all to be employed on the occasion, in a separate camp near the railway station was therefore seriously considered, but before putting it into execution a final effort was made to bring the stand to the camp, and by dint of hard work and relays of oxen the task was happily accomplished after nearly ten hours of incessant labour.

It was originally intended to use the prismatic camera with the 12″ cœlostat and to employ the stand for carrying a number of photographic objectives for pictures of the corona. This programme had to be abandoned owing to the late arrival of both the telescope and the cœlostat and particularly as it was found that the clock of the cœlostat required extensive alterations.

The telescope was mounted on a concrete foundation previously prepared for the purpose. The instrument as ready for the eclipse is shown in Plate VII. No observatory was constructed to house the instrument, the essential parts being usually kept covered with cloth to protect them from dust.

The clock gave much trouble and it was only by putting an excessive weight on the declination axis that a comparatively steady motion was finally secured.

As there was no shutter for making exposures, the prism-end of the telescope was enclosed in a box of thin wooden planks covered with enamelled cloth and the exposures were made by moving a card-board in front of the open end of the box. Mr. B. K. Báná, B.Sc., (student) who was told off for this important duty, had to be perched up on a platform ten feet high, which was by no means a very steady one, formed out of packing cases in the camp.

## *VIII.—The Slides employed.*

The slides were $14\frac{1}{2}''$ long by $13''$ broad, each carrying four $12'' \times 3''$ plates. The slides fitted into a carrier $24''$ long by $15''$ broad and were brought into the right position for each exposure by a rack and pinion. It was, however, found in actual practice that considerable time was lost in working the rack by means of the pinion head; a winch handle was therefore attached to the pinion, which saved several seconds in working the slides. As each plate came into position a spring catch held the slide securely into its place, from which it could not move until the catch was pushed back by hand. The serial numbers of the plates and the times of exposure were painted in bold figures on each slide.

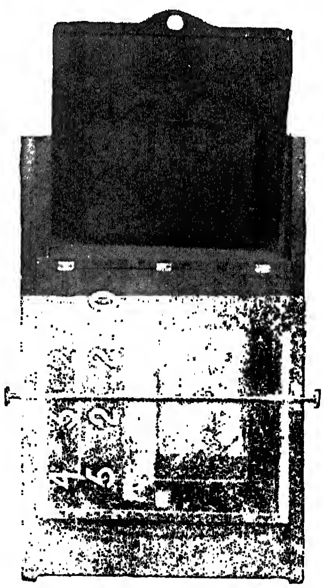

*Fig. 4 : Slide used with the prismatic camera.*

Seven exposures were given on two such slides during the first eighty seconds of totality. Another separate carrier and slide were employed to record the gradually changing spectrum at the end of totality. This carrier had a slit $\frac{1}{8}''$ broad, which was adjusted in such a position as to transmit the flash at the third contact

and the slide carried a 12″×10″ running-plate on which it was hoped that the changing spectrum would impress itself without a break.

### *IX.—Methods of Adjustment and Focussing.*

Ordinary astronomical objectives when out of square show an inward coma, *i. e.*, one in which the flare lies inwards towards the optic axis. With such objectives to see whether it is correctly adjusted or not the telescope is usually directed to a suitable star and the image is observed with a medium eye-piece. If the objective is not square a fan shaped appearance of a very appreciable size instead of a minute spurious disk is seen and this appearance is not got rid of in any position of the eye-piece. As is well-known, this fault is corrected by pushing the cell out on the side where the flare appears and the final adjustment is accomplished when the star-image slightly out of focus is seen surrounded by perfectly concentric interference rings.

This method of squaring, however, is not admissible in the case of the Cooke Triple Achromatic, as no amount of tilting within reason will make it show any side-flare. The following method was therefore employed to which my attention was first drawn by Professor W. W. Campbell. It is one of general application, if we take care to note all the images reflected from the component lenses of an objective and bring them into coincidence. It has moreover the great advantage of saving time, as it makes the astronomer independent of the state of the weather and the sky. The *modus operandi* is described as follows by Messrs. T. Cooke & Sons :—" It is a method whereby the sixth or back surface of the objective can be made to face the eye-piece accurately and squarely by a reflection test. Of course, if the back surface is accurately squared on, then all the other surfaces follow suit.

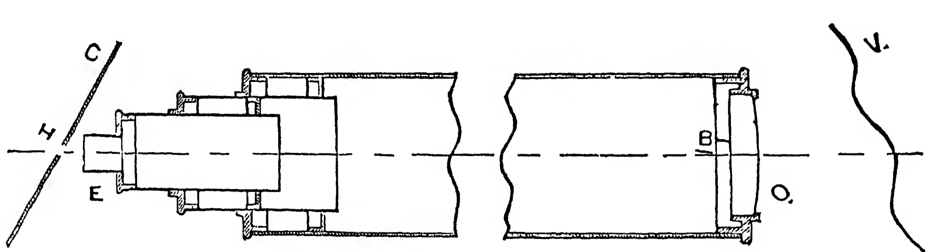


*Fig. 5 : Optical method of squaring an objective.*

" We will explain the method by means of the accompanying diagram (Fig. 5) where O is the objective and E the eye-end, with eye-piece taken out.

" First a piece of dark material V such as velvet or dark brown paper is held up in front of the objective and at some distance in front of it. The object of this is to furnish a dull back-ground against which the eye, placed at the eye-end, may see

the aperture of the objective as a circular gray patch of light. Then a piece of white card C with a hole H, about one-fifth inch diameter, is held diagonally behind the eye-piece and in front of the eye, so that the eye may view the objective through the hole. This card must be brightly illuminated, when a reflected circular image of the eye-end aperture, showing fairly white and with a black spot in its centre corresponding to the hole, should be visible in the back surface of the objective. This image will have an apparent diameter equal generally to about one-eighth part of the apparent size of the objective. It will not be easily seen if the back-ground V is too pale or too brightly illuminated. Now if the objective is correctly squared on, then the bright circular image of the eye-end aperture should appear exactly in the centre of the objective. If it is not, but is displaced towards the right hand, then the objective must be tilted outwards on the same side by means of the antagonist screws of the counter-cell and *vice versâ*. When giving the final adjustments it is important that the observer should keep the hole in the eye-screen exactly in alignment with the axis of the tube. He can easily see whether he is right in this respect by watching the reflected image, which should show like a circular white patch enclosing a dark spot which will appear exactly in its centre if the eye-hole is upon the axis of the tube. Should one of these objectives show any coma or side-flare under any circumstances, it would indicate that one of the component lenses had got slightly out of square with respect to the other two."* This method of squaring the lens was found in practice both easy and delicate of operation.

The polar axis was adjusted for the proper elevation of the pole by the method of Schaeberle, which is thus described by Professor Campbell in his "Elements of Practical Astronomy," pp. 215-216 :—

"Across the object end of the telescope firmly tie a piece of wood which projects several inches from the telescope tube on the side opposite the pier. Pass a fine thread through a very small hole in the projecting end and fasten it. Direct the telescope to the zenith. Near the eye-end and on the same side as the projecting arm fasten a block of wood. To this screw a metal plate so that it will be perpendicular to the axis of the tube and in which is a very small circular hole as nearly as possible (by estimation) under the hole above. Pass the thread through it, tie a plumb-bob to the end of the thread near the floor and let it swing in a vessel of water. Move the telescope by the slow motion screws until the plumb-line passes through the centre of the lower hole. Read both verniers of the hour and declination circles. Unclamp, hold the plumb-bob in the hand to avoid displacing the metal plate, reverse the telescope to the other side of the pier and set it so that the plumb-line again passes centrally through the hole. Read both circles as before.

"Let $H$ equal the angle of elevation of the polar axis. The difference of the readings of the declination circle in the two positions is $180° - 2H$. The elevation should equal the known latitude $\phi$. The error is $H - \phi$. Change the last circle reading by this amount by moving the telescope in declination in the proper direction. Adjust the angle of elevation by the proper screws until the plumb-line again passes through the centre of the hole.

* On the adjustment and testing of telescopic objectives. (Second Edition, 1896, pp. 57-58.)

"If the declination circle is graduated so as to read from 0° to 90° in both directions from its two equator points, then the mean of the circle readings for the two positions of the telescope is at once the inclination of the polar axis to the horizon.

"The mean of the hour circle readings in the two positions is the reading of the circle when the telescope is in the meridian. This should be $0^h\ 0^m\ 0^s$. The index error of the hour circle is the mean of the readings minus $0^h\ 0^m\ 0^s$ (or minus $24^h\ 0^m\ 0^s$). To correct for it, set the circle at this mean reading; then move the vernier screws until the reading is $0^h\ 0^m\ 0^s$.

"The index correction of the hour circle is equal to the index error with its sign changed. If the error is not removed by adjusting the verniers, the index correction must be applied to every reading made with the hour circle, in order to obtain the true reading."

Having first properly secured the correct elevation of the polar axis, for the final adjustment in meridian a spot on the sun was brought on the cross-wires of the eye-piece and the telescope was set in motion by the clock. After a time the displacement on the cross-wires was observed; its correction in one co-ordinate, by moving the telescope stand with the fine motion provided for the purpose, set the polar axis in meridian, while the displacement in the other co-ordinate indicated the necessary change of rate of the clock. This was repeated several times till it was found that there would be no appreciable disturbance or trailing in the spectrograms.

These excellent methods of adjustment enabled me to devote the few remaining nights in securing the proper focus for the spectrograms.

The prisms were placed for obtaining a north and south dispersion as usually employed for stellar spectra, and the three remaining nights were utilised in getting the best focus with such of the available brighter stars as gave a Hydrogen spectrum. The position adopted for the prisms was of course not the best for the chromospheric arcs, but the over-lapping, as mentioned in Section III, was not such as to counterbalance the advantage gained in focussing by the method of stellar trails and the results obtained quite justified this disposition of the prisms.

## *X.—Personnel and programme.*

Dr. A. W. Thomson, Professor of Engineering in the College of Science, Poona, was in charge of the instrument and exposed the slides.

Mrs. Thomson noted the times of exposure of each plate with a stop watch.

Mr. B. E. Vachha, B.Sc., (student) handed the first two slides to Dr. Thomson.

Mr. P. E. X. Vaz (student) received the slides from Dr. Thomson.

Mr. A. F. Gonsalves (student) handed in the second carrier with its third slide.

Mr. T. B. Vakil adjusted the curtain which was used over the camera owing to the leaky condition of the camera and slides.

Mr. B. K. Bana, B.Sc., (student) exposed the objective-end of the telescope at signals from Dr. Thomson.

*Programme of Work.*

The plates employed were Edward's Snapshot Isochromatic, backed with an antihalation composition.

From a series of preliminary trials it was found that twenty seconds would be required to remove the first carrier and to replace it by the second with the running plate. As it was arranged to start this last plate twenty seconds before the end of totality, full forty seconds out of the available one hundred and twenty had to be reserved for the purpose. In the remaining eighty seconds only seven exposures could be made, and the programme was arranged as follows :—

| Exposures. | Time of commencement of exposure from the beginning of totality. | Duration of exposure. |
|---|---|---|
| Slide I.—Plate 1 ... ... ... | 0 second ... | Instantaneous. |
| Plate 2 ... ... ... | 5 " ... | 2 seconds. |
| Plate 3 ... ... ... | 10 " ... | 2 " |
| Plate 4 ... ... ... | 15 " ... | 5 " |
| Slide II.—Plate 5 ... ... ... | 32 " ... | 5 " |
| Plate 6 ... ... ... | 40 " ... | 30 " |
| Plate 7 ... ... ... | 70 " ... | 10 " |
| Slide III.—Running Plate No. 8 ... | 100 " ... | 20 " before end of totality to several seconds after totality. |

The first four plates were exposed correctly. The second slide was not got into place quickly enough, but the three plates, Nos. 5, 6 and 7, were properly exposed. The shutter of this slide, however, did not shut easily, and some seconds were lost. It was afterwards found that one of the wooden rebates had come off and jammed the shutter. The force required to close the slide had shaken the instrument and displaced the image, and the spectrograms obtained on the running-plate were, therefore, not at the proper point of third contact.

The object of taking the first plate was to secure the "flash," which, after the successful attempt of Shackleton at Novaya Zemlya in 1896, it was deemed of prime importance to obtain. The running plate was also employed with the same object in view in order to secure the changing spectrum at the end of totality till it merged into the ordinary Fraunhofer spectrum.

## *XI.—Description of the Photographs.*

The first plate was taken at the instant when the "flash" was observed by me in an opera-glass spectroscope and the signal called out. At least one second must have elapsed between the observation and the commencement of the exposure.* The spectrum extends from $D_3$ to $H_\eta$ in the ultra-violet. The spectrum is sharpest in the vicinity of $H_\beta$. Owing to the want of perfect isochromatism in the plates employed the impression is fainter between $D_3$ and $H_\beta$ than in the rest of the spectrum. It gives hundreds of arcs of the upper and lower chromosphere and the continuous corona spectrum is also slightly impressed above and below the spectrum of the "flash." Several prominences are seen attached to the longer arcs, and one large prominence on the side still covered by the moon is photographed in Hydrogen, Helium and Calcium radiations. The Calcium arcs H and K are the longest, next come those of Hydrogen, then of Helium, these are followed by two exactly similar arcs of Strontium, then come numerous arcs of Magnesium, Iron, Calcium, &c., followed by a long series of arcs all of very nearly the same dimensions.

In the following table the principal arcs are given in descending order :—

| Flash-spectrum arcs. | Their lengths. | Their heights in seconds of arc. | Their heights in miles. |
|---|---|---|---|
| Calcium (H and K) ... ... ... | 115° | 10·0 | 4,436 |
| Hydrogen ... ... ... ... ... | 105° | 8·4 | 3,726 |
| Helium (*f*) 4471·6 ... ... ... | 90° | 6·3 | 2,795 |
| Strontium 4077·8 and 4215·7 ... ... | 65° | 3·4 | 1,508 |
| λ 4415·9 (?), 4418·5 (Ti), 4443·9 (Ti)... | 60° | 2·9 | 1,287 |
| λ 4026·2 (He), 4226·9 (Ca), 4233·5 (Fe), 4247 (?), 4375 (?), 4383·7 (Fe), 4395·2 (Ti), 4533·4 (Ti), 4548·9 (Ti), 4556·6 (Ti), 4562·8 (Ti), 4571·2 (Mg), 4582·9 (?), 4713·3 (He) ... ... | 55° | 2·4 | 1,065 |
| λ 4275 (?), 4290·3 (Ti), 4294·3 (Ti, Fe), 4300·2 (Ti), 4303·3 (?), 4313·03 (Ti), 4315·3 (?), 4321·1 (Ti), 4325·9 (Fe), 4501·4 (Ti) ... ... ... ... | 50° | 2·0 | 887 |
| λ 4508·4 (Fe ?), 4515·8 (Ti), 4922·4 (Cr), 4932·8 (?), 5172·8, $b_2$, (Mg), 5183·8, $b_1$, (Mg) ... ... ... ... ... | 45° | 1·6 | 710 |
| λ 4045·9 (Fe) ... ... ... ... | 35° | 1·0 | 444 |
| λ 4628·1 (?) ... ... ... ... | 30° | 0·7 | 311 |
| Numerous other arcs ... ... ... | 25°—20° | 0·5 to 0·3 | 222 to 133 |

* From a comparison of the plate with the excellent series of flash-spectra obtained by Sir N. Lockyer I am confirmed in this belief.

A detailed discussion of the arcs is given in a subsequent section, and it is sufficient here to remark that, as already pointed out by Sir Norman Lockyer and Captain Hills, the spectrum of the "flash" does not correspond in all particulars with the Fraunhofer spectrum and the latter, as daily observed, is not an exact reversal of the spectrum of the flash. This point was for a number of years urged by Lockyer, but, apart from an explanation of the cause, the proof positive so long wanting in support of Lockyer's contention was for the first time forthcoming in the unerring photographs of this Eclipse (see Plate X). Photographs of the "flash" at second contact are reproduced on Plates VIII and IX.

If further proof was wanting that the varying lengths of the arcs are truly indicative of the existence of some of the chemical elements at heights not reached by others in the solar atmosphere, it is afforded by a comparison of the first photograph of the "flash" with the second which was taken five seconds after the first (see Plate IX, fig. 2). In it the number of arcs is smaller and many of the metallic arcs of the first photograph are scarcely discernible; but one must not lose sight of the important fact that the vast majority of the bright lines as photographed in the first plate, which would go to produce the greater portion of the Fraunhofer spectrum, forms a well defined layer of almost the same depth and this may be taken not unnaturally as the chief region of reversal. A great part of the flash spectrum is still in evidence on the second plate (Plate IX, fig. 2), and taking the eight seconds as the duration of the flash we obtain for the depth of the "reversing-layer" an average thickness of 1,300 miles, which is nearly the same as that previously estimated.*

The third plate was under-developed and excepting a few of the principal long arcs nothing of importance is discernible on this plate.

Plate No. 4 taken fifteen seconds after totality was fully developed. This is reproduced on Plate IX, fig. 3. It shows a portion of the green coronal arc in the north-east quadrant, which is broad and diffuse. The continuous coronal spectrum shows two maxima, one between $D_3$ and 1474 K near E and the other between $H_\beta$ (F) and *f*. These maxima of intensity are due to the peculiar chromatism of the plate employed, whose curve of intensity as given by Mr. Sanger Shepherd † is reproduced below :—

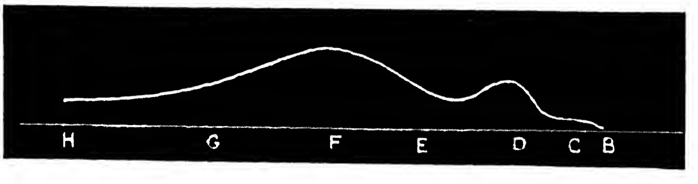


*Fig. 6 : Intensity curve of Edward's Isochromatic Plates.*

* Young's Sun, page 82.
† Journal of the Camera Club, Vol. XII, page 181.

On this plate besides the arcs H and K (Calcium) and those of Hydrogen and "*f*" of Helium, faint arcs of Titanium at λ 4395, 4443, 4533 and 4549, of Helium at 4713 and of Magnesium at 5173 ($b_2$) and 5184 ($b_1$) are faintly visible. These radiations, therefore, extend to about two thousand and five hundred miles above the photosphere.

Plates Nos. 5, 6 and 7 do not show anything which is not recorded on Plate No. 4, except that on these plates the H and K arcs of Calcium, and to a certain measure those of Hydrogen, more and more approach to complete circles owing to the further central advance of the moon on the solar disc. The rings of prominences in H and K radiations are thus nearly complete on Plate No. 7.

The running-plate, No. 8, ten inches long and twelve broad, was, in the words of Professor Thomson, "exposed twenty seconds from the end of totality and half run out at 'flash' (at third contact), then quickly turned until '*over*' was called." A slit $\frac{1}{8}''$ broad was placed in front of the plate where the third contact was calculated to occur. The rather strong shake received by the telescope in closing the second slide had apparently disturbed the position of the slit, as no "flash-spectrum" is recorded in the middle of the plate. It has, however, impressed itself higher up, and had the rapidity of the plate been not over-estimated, the spectrum would have appeared throughout the length of the plate. It is best seen at the end of the run, when there must have been some delay in covering the telescope and ending the exposure (see Plate XI). Short exposures of about one-half second each at the interval of a second commencing about ten seconds before the end of totality and continued for ten seconds after third contact would have given a much more valuable and complete record of the changes. In the flash at the end, Hydrogen lines up to $H_\pi$ are recorded together with the Titanium lines at λ 3685·3 and 3759·4. A comparison of the "flash" spectrum at the two internal contacts, moreover, enables us in a very complete manner to separate the long arcs from the shorter ones. As the spectrum was too faint to be measured on the microscope, a paper milimeter scale was attached to the plate and the arcs read off by estimation. The wave-lengths of the fine sharp arcs have come out with great exactness, while the broad, diffuse arcs whose middle points could not be easily bisected by eye-estimation were on the other hand the best known and therefore easily determinable. The origin of some of the arcs could not be determined from an inspection of Rowland's tables, but their true wave-lengths were estimated from the deviations of the actual measures of well-known neighbouring arcs from their respective true wave-lengths.

The following table gives the wave-lengths of these arcs together with their origin; by deducting these from the arcs recorded in the flash on Plate No. 1, (*vide* Section XIV), we can very safely attribute the great majority of the remainder to the low-lying uniform reversing-layer:—

| Wave-length. | Origin. | Character of corresponding arcs in Flash, Plate I. |
|---|---|---|
| 3685·3 | Ti. | |
| 3691·6 | $H_\pi$ | |
| 3703·9 | $H_\xi$ | |
| 3711·9 | $H_\nu$ | |
| 3721·8 | $H_\mu$ | |
| 3734·3 | $H_\lambda$ | |
| 3750·1 | $H_\kappa$ | |
| 3759·4 | Ti. | |
| 3770·7 | $H_\iota$ | |
| 3798·0 | $H_\theta$ | |
| 3829·5 | Mg. | |
| 3832·4 | Mg. | |
| 3835·6 | $H_\eta$ | |
| 3889·1 | $H_\zeta$ | |
| 3903·1 | Fe-Cr. | |
| 3913·6 | Ti. | |
| 3933·8 K. | Ca. | v.l. 115° |
| 3944·1 | Al. | f. 50° |
| 3961·6 | Al. | l. 50° |
| 3968·6 H. | Ca. | v.l. 115° |
| 4027·5 | ? | |
| 4045·9 | Fe. | l., t. 35° |
| 4077·8 | Sr. | v.l., D. 65° |
| 4101·8 | $H_\delta$ | v.l. 105° |
| 4215·6 | Sr. | v.l., D. 65° |
| 4227·8 ? | Ti. | |
| 4247·4 | ? | l., sh. 55° |
| 4254·5 | Cr. | l., sh. 55° |
| 4291·1 | Ti. | |
| 4300·2 | Ti. | l. 50° |
| 4303·3 ? | ? | l. 50° |
| 4308·0 | Fe. | v.l., b. |
| 4313·0 | Ti. | l. 50° |
| 4321·8 } 4321·9 } | Ti. } Fe. } | l. 50° |

| Wave-length. | Origin. | Character of corresponding arcs in Flash, Plate I. |
|---|---|---|
| 4325·9 | Fe. | l. 50° |
| 4340·6 | $H_\gamma$ | v.l., b. 105° |
| 4374·9 | Ti. | l. 55° |
| 4383·7 | Fe. | l., b. 55° |
| 4395·2 | Ti. | l. 55° |
| 4401·4 } 4401·6 } ? 4401·7 } | Fe. Fe. Ni. | l. |
| 4418·5 | Ti. | l. 60° |
| 4430·7 | Fe. | s. |
| 4444·7 | Ti. | l. |
| 4471·6 | He. | v.l. 90° |
| 4501·4 | Ti. ? | l. 50° |
| 4509·2 | ? | l. 45° |
| 4518·8 | Ti. | v.s., f. |
| 4525·3 | Fe. | |
| 4534·9 | Ti. | |
| 4550·9 | Fe. ? | |
| 4555·6 | Ti. | l., i.d. |
| 4568·9 | Fe. | |
| 4572·8 | ? | |
| 4582·9 | ? | l. 55° |
| 4719·3 | ? | |
| 4856·2 | Ti. | l. |
| 4861·5 | $H_\beta$ | v.l., b. 105° |
| 4885·6 | Fe. | |
| 4893·9 | ? | |
| 4927·6 | Fe. | |
| 4941·3 | ? | |
| 4974·3 | ? | |
| 5017·0 ? | Fe. | l. 45° |
| 5172·8 | Mg. | l. 45° |
| 5183·8 | Mg. | l. 45° |
| 5208·1 | Ti. | |

### *XII.—Monochromatic Images of Prominences.*

An enlargement of the prominences and the chromosphere underlying them in H and K radiations is given in Plate XII. This compared with the prominences as directly photographed by Dr. Copeland at Goghlee in the Central Provinces, India, with a 38 feet telescope (Plate XIII) shows with what success the forms of prominences can be recorded by the prismatic camera with the additional advantage that the prominences so photographed have not any portions of them submerged in the light of the corona.

### *XIII.—The Spectrum of the Flash; Reversing Layer.*

The question "What does the spectrum of the 'flash' signify?" is one for which an answer should be sought in any investigation of eclipse phenomena.

The dark line Fraunhofer spectrum is indeed produced in the region between the photosphere and the corona. Below the corona is the scarlet chromosphere with prominences, the detailed spectrum of which has been so successfully investigated by Young. It is therefore between the general surface of the photosphere and the chromosphere that the vast majority of the Fraunhofer lines should originate. This is the "reversing layer" of Young. In connection with this view Professor Young says: "It follows that this atmosphere, containing in gaseous form the substances whose presence is manifested by the dark lines of the ordinary spectrum, would give a spectrum of bright lines if we could isolate its light from that of the photosphere. The observation is possible only under peculiar circumstances. At a total eclipse of the sun at the moment when the advancing moon has just covered the sun's disk, the solar atmosphere of course projects somewhat at the point where the last ray of sun-light has disappeared. If the spectroscope be then adjusted with its slit tangent to the sun's image at the point of contact, a most beautiful phenomenon is seen. As the moon advances making narrower and narrower the remaining sickle of the solar disk, the dark lines of the spectrum for the most part remain sensibly unchanged though becoming somewhat more intense. A few, however, begin to fade out and some even turn palely bright a minute or two before the totality begins. But the moment the sun is hidden, through the whole length of the spectrum, in the red, the green, the violet, the bright lines flash out by hundreds and thousands, almost startlingly; as suddenly as stars from a bursting rocket-head, and as evanescent, for the whole thing is over within two or three seconds. Except at an eclipse it has not yet been found possible to observe this bright line spectrum, because it is overpowered by the ærial illumination of our own atmosphere. It is not, however,

to be understood that the dark lines of the solar spectrum are due entirely, or even principally, to the stratum of gas which lies close above the surface of the photosphere. Were this so, the dark lines should be much stronger in the spectrum of light from the edges of the disk than in that from the centre, which is not the case; at least the difference is very slight. The photosphere is composed of separate cloud-like masses floating in an atmosphere containing the vapours by whose condensation they are formed; the principal absorption, therefore, probably takes place in the interstices between the clouds and below the general level of their upper limit."*

This view, as is well known, is strenuously opposed by the *doyen* of English solar physicists, Sir Norman Lockyer, who denies the existence of the reversing layer "in the sense that there is a thin stratum, close above the surface of the photosphere, in which most of the dark lines of the solar spectrum originate. He maintains on the contrary, in accordance with his dissociation theory, that certain of the lines due to substances the most nearly elementary and having their molecules in the highest state of dissociation originate only deep down in the solar atmosphere where the heat is most intense; others due to vapours with molecules somewhat less simple have their birth a little higher, and others due to molecules the most complex are produced only in the most elevated regions of the solar atmosphere; each elevation thus being responsible for its own especial family of spectral lines."† He has marshalled the facts in support of his view with conspicuous force in the "Chemistry of the Sun" and in his "Recent and coming Eclipses" and he sums up his conclusion in the words that the 'flash' gives us "a region of high temperature, in which there is a corresponding simplification of spectrum as compared with the cooler region in which the Fraunhofer absorption is produced."‡

The questions which first require answer are:—

(1) Is the 'flash' spectrum an exact reversed copy of the Fraunhofer spectrum?

(2) Is there a definite layer of gases in which, if not all, the vast majority of the Fraunhofer lines are represented?

(3) Can the spectrum, as evidenced in the 'flash,' without being an exact reversal of the Fraunhofer spectrum, produce the latter spectrum?

Regarding the first, there can now be no doubt that the two spectra differ in some most important particulars from one another. Many of the thin lines in one are strong in the other and *vice versâ* and not a few of the lines are altogether absent (see Plate X). In this respect there can be no question that Lockyer has fully established his contention.

But on the other hand we must answer the second question in the affirmative, that "if we except the ordinary chromospheric lines, all the fainter lines due to the flash spectrum are of the same length and form a well-defined band of even width

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* Young's Sun, pages 82-83. † Young's Sun, page 340.

‡ Recent and Coming Eclipses, 1890, page 111.

running from end to end of the spectrum. This shows that the low-lying gases at the base of the chromosphere form a well-defined layer pretty definitely bounded and not fading by insensible gradations into the higher portions of the chromosphere."* In the 'flash' we are looking tangentially through this layer, while in viewing the Fraunhofer spectrum we look through the entire thickness of the layer which very probably reaches lower depths of the photospheric region; consequently we cannot expect a strict coincidence between the two spectra and we ought to be prepared for only a general coincidence. Moreover, as Stoney has remarked †: "The divergence between the intensities of the bright lines of the chromosphere and the corresponding dark lines of the ordinary solar spectrum was exactly what we had a right to expect. If we view a bright incandescent body which is opaque and which is interposed between the eye and the still brighter background, it appears dark in the contrast. In the same way when we admit to our spectroscope light from the face of the sun, we are looking through the chromosphere, filled with its bright lines, at the still brighter background of the intense continuous spectrum produced by the photosphere. Now it is a known property of incandescent gases to be more or less opaque for light of those particular wave-lengths which they can emit and which produce their bright lines. They thus intercept the bright light of those wave-lengths coming from the photosphere and substitute at these situations of the spectrum the feebler radiations which they themselves emit and which appear in the contrast as the dark Fraunhofer lines of the solar spectrum. Accordingly one dark Fraunhofer line is fainter than another, either because the chromospheric line which occasions it is intrinsically a brighter line, or because it is less opaque, or both. If it is brighter it looks less dark when contrasted with the background; if it is less opaque it allows some light from the bright background to come through. It thus happens that dark Fraunhofer lines which are faint are often caused by very bright lines in the chromosphere and *vice versâ.*" From this it follows that if there is no dark line corresponding to a bright one, it may be because it is itself as bright as the light behind it which it intercepts, and this is known to occur in the case of Helium and the ultra-violet Hydrogen lines which no doubt exist in the sun's chromosphere. This is also true in the case of the well-known laboratory experiment of Bunsen on the reversal of the sodium flame. If we, therefore, proceed from the known to the unknown, our third query is also answered in the affirmative.

Mr. Maunder has discussed with great ability and in the most judicial spirit this important point in *Knowledge* for August 1898. He also gives there a very lucid exposition of the phenomena to be expected with a prismatic camera in attempting to photograph the flash. I make no apology, therefore, in quoting at some length from his article:

"It may appear a very obvious truism to say that, at any moment during the eclipse, the spectrum which we obtain is the spectrum of that bright object which is exposed to our view

* Evershed in *Knowledge*, 1898, page 133.

† Journal of the British Astronomical Association, Vol. III, page 303.

at that moment; but it is a fact which has to be very clearly kept in mind. With a prismatic camera directed towards an eclipse in progress, the source of light is the whole of the phenomena—sun, chromosphere, prominences and corona—that at the moment of observation remain uncovered by the dark body of the moon.

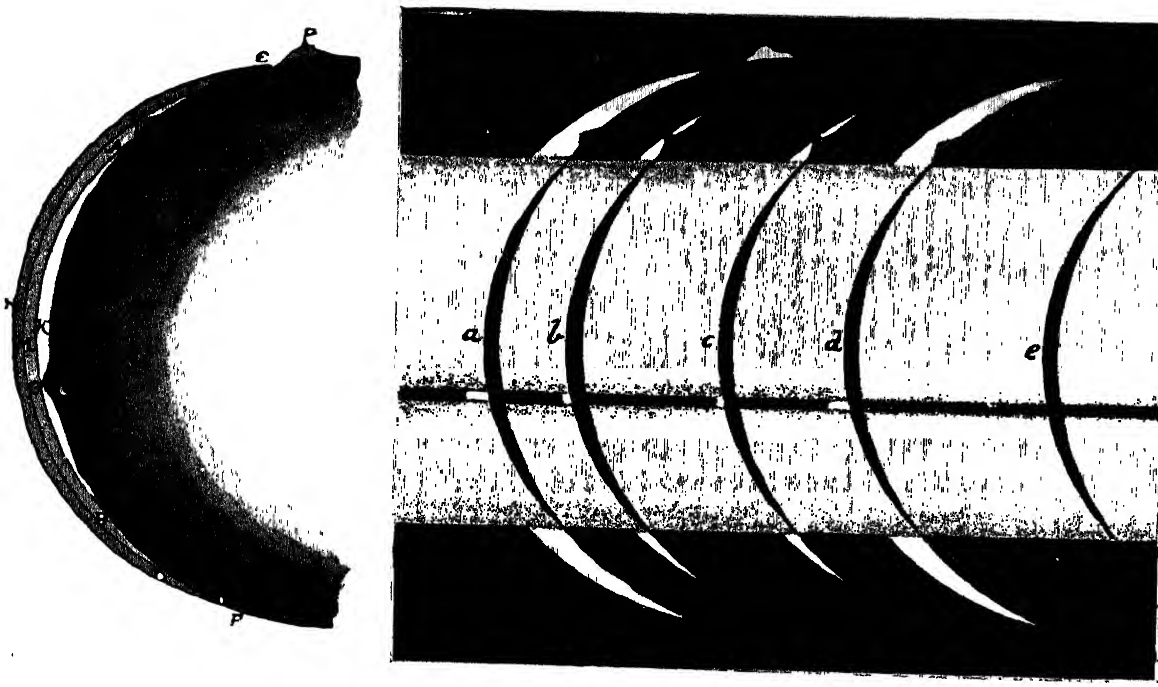


*Fig. 7 : Spectrum of solar eclipse just before totality with the prismatic camera. (Maunder.)*

"The accompanying diagram (Fig. 7) may serve to show just what it is which forms our source of light at the instant before second contact. Let the arc CABD represent the dark approaching limb of the moon. The arc AKB represents the limb of the sun, and, as we see, only a very narrow segment of sunlight remains still disclosed. Beyond the sun's limb, however, there is a gaseous envelope of which the chromosphere forms a part. For the sake of distinctness I have supposed this envelope to consist of two strata, an upper and lower, and we may consider the former as representing the chromosphere, the latter as representing the 'flash.'

"What is the appearance of the spectrum at this moment? The small arc of sunlight still remaining gives us, of course, a continuous spectrum, and it will be seen that this continuous spectrum must narrow very fast as the actual moment of totality comes on. This narrowing strip of continuous spectrum is of course crossed by the Fraunhofer lines, each of which is of the same general shape as the little arc of sunlight. But above and below this arc of sunlight we find the dark limb of the moon bordered only by the gaseous envelope. At the point of the cusps and a

little beyond, we have both strata, but the lower becomes narrower and narrower and terminates at C and D. The upper stratum can be traced further still, until it, too, is cut off by the lunar limb at E and F.

"These arcs, then, AC, CE, and BD, DF, being arcs simply of glowing gas, give us bright line spectra. The elements contained in each region will each give its own spectrum of bright lines, and these bright lines will each supply an image of the region over which that particular element is found. Above and below the continuous spectrum, therefore, with its arched Fraunhofer lines, we find a bright line spectrum of tapering horns of light of different lengths, and we see at once that the length of any arc is an index of the height above the sun to which that particular bright line can be traced.

"As the fateful instant approaches, the continuous spectrum narrows faster and faster; the bright horns above and below multiply and extend, and just at the last moment before totality is accomplished the continuous spectrum is invaded by a number of dark longitudinal lines, resembling the 'dust lines' in an ordinary slit spectroscope. The edge of the moon is, of course, somewhat rugged, and here and there a mountain peak or range will project right across the thread of sunlight which remains and interrupt the continuous spectrum at that point. But the effect is not quite that of an ordinary 'dust line,' for if the mountain, as at G, cuts out the sunlight, it does not cut out the gaseous envelope above. This is free, therefore, to yield its own bright line spectrum, and consequently we see our 'dust line' sparkling out here and there into stars of coloured light. H is an instance where a lunar mountain hides the lower gaseous spectrum and allows us only to see the upper. P, again, is the summit of a prominence which appears quite detached from the sun, since its base is hidden by the moon. It therefore shows itself in the spectrum by a row of tiny coloured images of itself, shining like stars, quite detached from the remainder of the spectrum. In most prominences these will be the lines of Hydrogen, Helium and the celebrated H and K lines.

"The crisis is at hand: the interruptions which I have likened to 'dust lines' multiply and broaden. The intervening continuous spectra are worn down to thinnest threads, then snap and vanish, and totality has come. The tiny stars which broke up the 'dust lines' flash out as a long sequence of little arcs of colour, and shine for a second or perhaps two ere the encroaching dark limb of the moon covers the stratum to which they belong and hides them from us. That brief, brilliant glimpse of little bright line arcs is what is known as the '*flash*,'—'the so-called flash,' as certain over-cautious writers have termed it, in the spirit of him who censured the manners of this 'so-called nineteenth century.' '*Flash*' it is—a most wondrous and beautiful sight, be its explanation what it may.

"The 'flash,' then, represents a shallow stratum of glowing gases immediately surrounding the sun. The height to which any particular gas can be traced can be determined in three ways: first, by the length of the bright line arc beyond the cusp which it shows at any particular moment; next, by the length of time that the moon takes to hide the stratum; third, by the extent to which a given lunar mountain may interrupt the lines of the gas at a particular moment. In one way or another we find that, roughly speaking, the 'flash' corresponds to a stratum of some seven hundred miles in depth.

"When Professor Young first saw the 'flash,' he considered that the bright lines seen by him corresponded with the ordinary Fraunhofer lines, and he remarks that though 'it would be very rash on the strength of such a glimpse to assert with positiveness that these innumer-

able lines corresponded exactly with the dark lines of the spectrum,' yet that the general appearance and grouping of the lines in the spectrum seemed perfectly familiar to him. Mr. Pye, who observed the same eclipse and also saw the 'flash,' says that the effect was 'as if all the dark lines were converted into bright ones.'

"Spectroscopists have, as a rule, been content to accept the 'flash' as in all probability practically a reversal of the Fraunhofer lines. Sir Norman Lockyer, whilst objecting to it, thus clearly states the ordinary view as to the '*reversing layer*':—

(1) We have terrestrial elements in the sun's atmosphere.

(2) They thin out in the order of vapour density, all being represented in the lower strata, since the temperature of the solar atmosphere at the lower levels is incompetent to dissociate them.

(3) In the lower strata we have especially those of higher atomic weight, all together forming a so-called 'reversing layer,' by which chiefly the Fraunhofer spectrum is produced.—('Chemistry of the Sun,' page 303.)

"It follows that, on this view, the spectrum of the base of the solar atmosphere should most resemble the ordinary Fraunhofer spectrum (*ibid*, page 306). In 1873, however, Professor Lockyer was led to take an entirely different view, and he was convinced 'that the absorption took place at various levels above the photosphere'—('Recent and Coming Eclipses,' page 99). On this latter hypothesis, the different vapours exist normally at different distances above the photosphere, according to their powers of resisting the dissociating effects of heat. It follows that 'the spectrum of the base should least resemble the Fraunhofer spectrum, because at the base we only get those molecules which can resist the highest temperatures.'

"The immense importance of the spectrum of the 'flash' becomes at once apparent. Upon its characteristics and upon their interpretation stand or fall our whole conceptions of the chemical constitution of the sun. For the 'flash' is the revelation of the spectrum of the base of the sun's atmosphere within the limits of the powers of our present instruments. A depth of seven hundred miles is an enormous one in any atmosphere, and especially in that of the sun, and must include a vast range of conditions, both of pressure and temperature; but we are at present compelled to treat it as an indivisible integer. Keeping this fact in view, that the seven hundred miles of depth of the 'flash' stratum must include a great number of very distinct minor strata, of which only the lowest can, on the old hypothesis, be in complete correspondence with the Fraunhofer spectrum, it is clear that we can test the rival claims by watching whether or no, as totality comes on, the ever-increasing bright horns which appear above and below the continuous spectrum are the reversals of the dark Fraunhofer arcs. On the old hypothesis, the multiplying bright lines should ever be approaching complete correspondence with the Fraunhofer spectrum up to the moment of commencement of full totality; on Lockyer's hypothesis, they should ever be diverging further from it. The conditions of observation preclude us at present from following out the process to its minutest and final detail. All we can do—and it is sufficient—is to mark in which direction the tendency lies.

"It is this question of the direction of progress which is the crucial one—whether as we get nearer the base of the solar atmosphere, the bright line spectrum becomes more and more, or less and less, accordant with the Fraunhofer spectrum. It is not a question of establishing a complete and exact correspondence: that we could not expect. Nor is it a question of the relative

intensities of the lines. With that question we are not yet competent to deal. It has been generally assumed (Sir Norman Lockyer asserts it nakedly) that the relative intensity of the bright lines of the spectrum of any element in the laboratory ought to be the same as that of those same lines when dark in the Fraunhofer spectrum. Dr. Johnstone Stoney has recently reminded us how wholly unwarranted this assumption is; for if, as he puts it, we observe the spectrum of some source of white light through a sodium flame, and therefore see the D lines dark in a continuous spectrum, and then increase the brilliance of the sodium flame, we diminish the intensity of those dark lines.

"Dr. Stoney also points out that a difference of intensity between the bright line and the dark line spectrum may be due to the gas being present in but very small quantities. Thus, the $D_3$ line of Helium is very brilliant as a bright line in the chromosphere, but is normally absent as a dark line from the spectrum of the disc. We cannot tell certainly whether this is due to the Helium being so bright as to emit as much light as it absorbs from the sun, or whether it is so tenuous as practically to absorb nothing when we look at the sun through it, and only reveals itself at the limb in consequence of the vastly greater depth we look through: or a combination of the two factors may supply the complete explanation. For myself, believing as I do that any true solar atmosphere must be limited to a very few miles above the photosphere, and that chromosphere and prominences, however magnificent in appearance, are of the last degree of tenuity, I am disposed to put much stress upon the second suggestion. The phenomena of comets' tails might remind us how brilliant and far-reaching a body may be without any real substance. Indeed, the corona itself is a case in point. We look down upon the sun day by day through millions of miles of depth of its strange, complicated structure, and are not able to recognize the faintest sign of its presence."

Under these circumstances we are bound to say that the true explanation of the '*flash*' in relation to the Fraunhofer spectrum is still *sub-judice*.

### *XIV.—Lines in the Flash Spectrum.*

The spectrum on Plate No. 1, taken with the six-inch prismatic camera, is not very sharp. This is due to some slight want of focus, the very brief time at my disposal having prevented me from attaining a greater precision. The measurement of the arcs from which directly the wave-lengths have been obtained was, therefore, a very tedious process, and the uncertainties in the bisection of the lines were of an order higher than the precision with which divisions could be read off on the micrometer-microscope. The resulting wave-lengths are in consequence affected by varying degrees of uncertainty depending upon the widths of the arcs and the precision with which their bisection could be estimated by the eye; the difficulty in making these eye-estimates was increased owing to the arcs being more diffuse on the red side than on the violet. Notwithstanding these drawbacks a high degree of precision has been reached in determining most of the wave-lengths. The spectrum was measured in two sections from *K—f* and *f—b*, and the excellent formula of Cornu-Hartmann was employed for interpolation by the method of least squares.

The plate was measured on a micrometer-microscope by Hilger provided with a milimeter screw having a run of sixteen centimeters; its large micrometer head 12·5 centimeters in diameter is divided into one hundred parts, and by the substitution of a vernier plate for the index, one-fifth of a division could be read off directly and one-tenth by estimation. A distance equal to one five-hundredth of a milimeter can be thus read off on the micrometer directly and half that amount by eye-estimation. There is no fast motion to the microscope, and the stage originally supplied was a simple brass plate without any mechanical device. Particularly with long spectrograms the lengths of the spectra are seldom exactly parallel to the edges of the glass plates, the slightest play in the camera slide causing a deviation. This is, as a rule, of no great moment in the case of stellar spectra as they are made up of straight lines, but in the case of solar eclipse spectra where the lines are replaced by arcs and these arcs not symmetrical with reference to the direction of dispersion, it is absolutely necessary to measure the arcs in the same horizon of the spectrum. A perfect rectification of the spectrum parallel to the micrometer screw is therefore indispensable. To attain this adjustment with a microscope which had to be run through 160 turns from end to end several times was not only a tedious but highly undesirable method to adopt. A mechanical stage was, therefore, devised. Its lowermost plate, twelve inches long, fixed on the stand had its two extreme edges turned to a radius of six inches: on this another plate was made to turn with its centre of motion in the middle of the length of the stage, it being kept in position by side pieces which clamped on the lower plate. A spectrum plate can be thus given any inclination and put parallel to the long micrometer screw. In practice, however, it was found that the upper plate had a little play, and as no central pivot could be fixed to guide it, the spectrogram shifted in position and the final adjustment could not always be made quite accurately. This want of constancy was overcome by a simple expedient to be mentioned below. The rotating stage-plate is provided with a twelve-inch slide moving parallel to the length of the screw, and this first slide has another nine-inch slide moving at right angles to the screw on which the spectrogram is clamped. With the microscope in the centre of the run, it is, therefore, only necessary to bring any point on the spectrum under the cross-wires by adjusting the second slide and then move the first slide from end to end; any want of parallelism is thus at once detected, which is rectified by rotating the stage. The second slide is provided with a bent spring $6\frac{1}{2}$ inches long which presses against one side of the glass plate and is opposed by two screws on the other side. Slight deviation from parallelism in the spectrum is removed by working these opposing screws and the glass plate is finally clamped. After the experience gained with this stage, it seems that the rotating part of the stage might have been altogether dispensed with, depending wholly on the spring and opposing screws to bring about the parallelism.

*Table of wave-lengths of arcs determined in the Flash Spectrum Plate I.*

Column I gives the wave-lengths as directly calculated; in column II are given the probable true wave-lengths, the majority of which have been found from Rowland's Tables; column III gives the characters of the arcs; column IV Rowland's "intensity numbers" for lines adopted from his tables; and column V their origin.

Explanation of abbreviations used:—

*b* = broad.
*D* = dark.
*dif* = diffused.
*f* = faint.
*h* = hazy.
*i.d.* = ill defined.
*l* = line, meaning a long arc.
*s* = short.
*sh* = sharp.
*sl. ex.* = slightly extended, being not so long as "*l*."
*t* = thick.
*v* = very.

*Cooke Spectrograph, Plate I.*

| I. Calculated wave-lengths. | II. Probable wave-lengths. | III. Character of arcs. | IV. Rowland's intensity numbers for Fraunhofer lines. | V. Elements. | VI. Remarks. |
|---|---|---|---|---|---|
| 3932·25<br>3937·62 | 3933·825 K | *v.l, b.*<br>*v.l, b.* | 1000 | Ca. | Beginning and end of K. Mean of the two extreme readings is 3934·93. Arc is sharp on violet side. |
| 3939·60 | 3940·183 | *v.s, f.* | 2 | Fe. | |
| 3943·85 | 3944·160 | *v.s, f.* | 15 | Al. | |
| 3944·91 | 3944·884<br>3945·033 | *v.s, f.* | 2<br>3 | Fe. | |
| 3950·40 | 3950·497 | *s, f.* | 2 | Y. | |
| 3951·33 | 3951·311 | *s, v.f.* | 5 | Fe. | |
| 3952·96 | 3953·043<br>3954·120 | *s, v.f.* | 3<br>3 | Mn.<br>Co. | |
| 3956·21<br>3959·45 | 3956·476<br>3956·603<br>3956·819<br>3957·177<br>3958·355 | Hazy band. | 4<br>4<br>4<br>7<br>5 | Ti.<br>Fe.<br>Fe.<br>Fe. Ca.<br>Ti. Zr. | |
| 3961·82 | 3961·674 | *l.* | 20 | Al. | Evidently double. |
| 3967·25<br>3972·39<br>3974·27 | 3968·625 H | *v.l, b.* | 700 | Ca. | Beginning of H. being sharp on violet side.<br>End of dark part of H.<br>End of H. |
| 3982·85 | 3982·630<br>3982·742 | *s, dif.* | 2<br>3 | Ti. Mn.<br>Y. | |
| 3992·27 | ...... | *s, v.f.* | ... | ... | |
| 3998·68 | 3998·790 | *b, i.d, s.* | 4 | Ti. | |
| 4005·82 | 4005·408<br>4005·856 | *b, i.d, s.* | 7<br>3 | Fe. | |
| 4012·73 | 4012·541 | *s, t, D.* | 4 | Ti. | Probably a double. |
| 4015·21 | ...... | *s, t, f.* | ... | ... | Do. do. |
| 4022·10 | 4022·018 | *v.s, v.f.* | 5 | Fe. | |
| 4025·76 | .. ... | *l, f, dif.* | ... | ... | |
| 4028·87 | 4028·912 | *v.s, f.* | 1 | Fe. Ce. | |
| 4030·79 | 4030·878<br>4030·947<br>4033·224<br>4034·644 | *s.* | 4<br>5<br>7<br>6 | Mn.<br>Mn.<br>Fe. Mn.<br>Mn. Fe. | First line of a group of five. |
| 4035·81 | 4035·883 | *s.* | 4 | Mn. | Last line of a group of five. |
| 4041·33 | 4041·431<br>4041·525 | *s, t, dif.* | 3 | Fe.<br>Mn. | |

*Cooke Spectrograph, Plate I.*—(continued).

| I. Calculated wave-lengths. | II. Probable wave-lengths. | III. Character of arcs. | IV. Rowland's intensity numbers for Fraunhofer lines. | V. Elements. | VI. Remarks. |
|---|---|---|---|---|---|
| 4045·97 | 4045·975 | *l, t.* | 30 | Fe. | |
| 4048·96 | 4048·910 | *f, s.* | 5 | Mn. Cr. | |
| 4054·91 | 4055·023 | *v.s, v. dif, f.* | 3 | Fe. | |
| 4063·75 | 4063·759 | *sl.ex, t, D.* | 20 | Fe. | |
| 4067·49 | 4067·429 | *f, v.s, dif.* | 3 | Fe. | |
| 4072·07 | 4071·908 | *sl.ex.* | 15 | Fe. | |
| 4077·84 | 4077·885 | *v.l, D.* | 8 | Sr. | Centre of the dark line. |
| 4081·73 | 4081·736<br>4081·887 | *f, s.* | 0<br>0 | ?<br>? | |
| 4083·75 | 4083·715<br>4083·783 | *f, s.* | 2<br>4 | Fe.<br>Mn. Y. | Hazy band. |
| 4087·63 | ...... | *f, s.* | ... | ... | |
| 4093·14 | ...... | *v.s, v.f, i.d.* | ... | ... | |
| 4096·75 | ...... | *v.s, v.f, i.d.* | ... | ... | |
| 4101·70 | 4102·0 | *v.l, b.* | 40 | H. | Centre of very long arc. |
| 4105·82 | ...... | ...... | ... | ... | |
| 4109·90 | 4109·92<br>4109·953 | *s, t, hazy.* | 3 | Ti.<br>Fe. | |
| 4119·15 | 4119·050 | *s, t.* | 2 | Fe. | |
| 4121·15 | 4120·937 | *s, i.d.* | 3 | He. | Band. Mean of the two extremes 4123·19, one of the strongest Lanthanum lines has λ 4123·381. |
| 4125·24 | ...... | *s, i.d.* | ... | ... | |
| 4128·49 | 4128·20<br>4128·251 | *s, D, i.d.* | 3<br>6 | Ti.<br>V. | First of five lines. |
| 4130·33 | 4130·196 | *s, D, i.d.* | 2 | Fe. | |
| 4132·88 | 4132·690<br>4132·863<br>4133·062 | *s, D, i.d.* | 3<br>1<br>4 | ?<br>?<br>Fe. | |
| 4135·41 | 4134·840 | *s, D, i.d.* | 5 | Fe. | |
| 4137·95 | 4137·809 | *s, D, i.d.* | 1 | Fe. Ce. | Last of five lines. |
| 4143·96 | 4144·038 | *D, sl.ex.* | 15 | Fe. | |
| 4149·93 | 4149·923 | *s, D.* | 2 | ? | |
| 4152·75 | ...... | *s, i.d.* | ... | ... | |
| 4154·80 | 4154·667<br>4154·824<br>4154·976 | *s, i.d.* | 4<br>...<br>4 | Fe.<br>C. ?<br>Fe. | |
| 4157·09 | 4156·970 | *s, i.d.* | 3 | Fe. | |
| 4161·84 | 4161·961 | *s, i.d.* | 1 | Sr. | |
| 4163·99 | 4163·818 | *s, i.d.* | 4 | Ti. | |
| 4167·92 | 4167·884<br>4168·025 | *v.s, v.i.d.* | 1<br>2 | C.<br>? | |
| 4173·17 | 4172·803<br>4172·923<br>4173·136 | *sl.ex.* | 2<br>4<br>1 | ...<br>Fe.<br>... | Middle of short band, evidently a group of three lines. |
| 4178·33 | 4178·223 | *sl.ex.* | 2 | ? | Middle of a group of three lines. |

*Cooke Spectrograph, Plate I.*—(continued).

| I. Calculated wave-lengths. | II. Probable wave-lengths. | III. Character of arcs. | IV. Rowland's intensity numbers for Fraunhofer lines. | V. Elements. | VI. Remarks. |
|---|---|---|---|---|---|
| 4182·29 | 4182·136 | s. | 2 | ? | Probably a double. |
| | 4182·518 | | 3 | Fe. | |
| 4185·19 | 4185·058 | s, i.d. | 4 | Fe. Cr. | |
| 4187·74 | 4187·747 | s. | 2 | Fe. | Probably a double. |
| 4191·93 | 4191·843 | s. | 3 | Fe. | |
| 4196·96 | 4196·837 | s, b. | 1 | Fe. | |
| 4199·20 | 4199·267 | sl.ex. | 5 | Zr. Fe. | |
| 4202·33 | 4202·198 | f, sl.ex. | 8 | Fe. | |
| 4205·42 | 4205·515 | s. | 1 | Fe. | |
| 4215·76 | 4215·703 | v.l. | 5 | Sr. | Middle of the dark part of a very long arc. |
| 4220·17 | 4220·212 | ...... | 1 | ? | |
| 4226·90 | 4226·904 | l, sh. | 20 | Ca. | |
| 4230·65 | ...... | ...... | ... | ... | |
| 4233·59 | 4233·328 | l, sh. | 4 | Mn. Fe. | |
| | 4233·772 | | 6 | Fe. | |
| 4236·34 | 4236·112 | f, sl.ex. | 8 | Fe. | |
| 4240·17 | 4240·014 | f, s. | 3 | Fe. | |
| 4243·20 | ...... | f, sh. | ... | ... | |
| 4247·14 | 4246·996 | l, D, sh. | 5 | Sc. | |
| 4250·84 | 4250·945 | f, sl.ex. | 8 | Fe. | |
| 4254·64 | 4254·505 | l, sh. | 8 | Cr. | |
| 4256·46 | 4256·287 | f, s. | 0 | Ti. | |
| | 4256·68 | | | Ti. | |
| 4258·54 | 4258·477 | s. | 2 | Fe. | |
| | 4258·68 | | 3 | Ti. | |
| 4260·90 | 4260·991 | sl.ex. | 0 | Ti. | |
| 4268·35 | 4268·266 | f, s. | 1 | ? | |
| 4271·81 | 4271·934 | l, sh. | 15 | Fe. | |
| 4275·12 | 4274·958 | l, sh. | 7 | Cr. | |
| 4280·31 | ...... | v.f, v.s. | ... | ... | |
| 4283·31 | 4283·169 | sl.ex. | 4 | Ca. | |
| 4290·36 | 4290·377 | l, sh. | 2 | Ti. | |
| 4294·33 | 4294·204 | l. | 2 | Ti. | |
| | 4294·301 | | 5 | Fe. | |
| 4297·24 | 4297·110 | sl.ex. | 2 | ? | |
| 4300·37 | 4300·211 | l. | 3 | Ti. | |
| 4303·33 | 4303·337 | l. | 2 | ? | |
| 4306·07 | 4306·078 | s. | 4 | Ti. | |
| 4308·10 | 4308·081 | v.l, b. | 6 | Fe. | |
| | 4310·266 | | 2 | ? | |
| 4310·46 | 4310·388 | sl.ex. | 1 | ? | |
| | 4310·540 | | 2 | ? | |
| | 4310·631 | | 1 | ? | |
| 4313·40 | 4313·034 | l. | 3 | Ti. | |
| 4315·28 | 4315·262 | l. | 4 | Fe. | |
| 4321·20 | 4321·119 | l. | 2 | Ti. | |
| 4325·98 | 4325·[illegible] | l. | 8 | Fe. | |

*Cooke Spectrograph, Plate I.*—(continued).

| I. Calculated wave-lengths. | II. Probable wave-lengths. | III. Character of arcs. | IV. Rowland's intensity numbers for Fraunhofer lines. | V. Elements. | VI. Remarks. |
|---|---|---|---|---|---|
| 4331·42 | ...... | *s.* | ... | ... | |
| 4334·59 | ...... | *s, t.* | ... | ... | |
| 4337·23 | 4337·216 | ...... | 5 | Fe. | Faint band on violet side of Hγ. |
| 4340·52 | 4340·634 | *v.l, b.* | 20 | H. | Centre of dark part of Hγ. |
| 4348·06 | 4348·003 | *s, h, b.* | 2 | Fe. | |
| 4352·12 | 4352·083 | *l.* | 5 | Mg. | |
| 4355·28 | 4355·257 | *s, h.* | 2 | Ca. ? | |
| 4359·69 | 4359·784 | *s, t, D.* | 3 | Cr. | Probably a double. |
| 4363·36 | 4363·267 | *s.* | 1 | Cr. | First of three lines. |
| 4370·64 | ...... | *s.* | ... | ... | |
| 4372·07 | ...... | *s.* | ... | ... | Last of three lines. |
| 4375·33 | 4375·103 | *l.* | 2 | V. Mn. | |
| 4383·89 | 4383·720 | *l, b.* | 15 | Fe. | |
| 4389·02 | ...... | *v.s.* | ... | ... | |
| 4391·80 | ...... | *s.* | ... | ... | |
| 4395·46 | 4395·201 | *l.* | 3 | Ti. | |
| 4398·55 | ...... | *s, i.d.* | ... | ... | |
| 4401·24 | 4401·183 | *l.* | 1 | ? | |
| 4405·34 | {4405·07<br>4405·86 | *l.* | ... | Ti.<br>Ti. | |
| 4409·29 | 4409·288 | *s.* | 1 | Fe. | |
| 4412·29 | ...... | *s.* | ... | ... | |
| 4415·96 | 4415·722 | *l.* | 3 | ? | |
| 4418·55 | 4418·499 | *l.* | 1 | Ti. | |
| 4423·39 | 4423·298 | *s, i.d.* | 1 | Fe. | |
| 4425·89 | 4425·608 | *s, i.d.* | 4 | Ca. | |
| 4428·11 | ...... | *sl.ex.* | ... | ... | |
| 4430·98 | 4430·785 | *s.* | 3 | Fe. | |
| 4435·92 | 4435·851 | *sl.ex.* | 4 | Ca. | |
| 4444·16 | 4443·976 | *l.* | 5 | Ti. | |
| 4447·96 | 4447·892 | *s.* | 6 | Fe. | |
| 4450·90 | 4450·654 | *sl.ex.* | 2 | Ti. | |
| 4455·62 | 4455·485 | *sl.ex.* | 2 | Ti. | |
| 4462·42 | 4462·165 | *sl.ex.* | 3 | Fe. Mn. | |
| 4465·37 | ...... | *sl.ex.* | ... | ... | |
| 4468·89 | 4468·663 | *l.* | 5 | Ti. | |
| 4471·65 | 4471·649 | *v.l.* | ... | He. | |
| 4474·38 | ...... | *s, i.d.* | ... | ... | |
| 4477·39 | ...... | *s.* | ... | ... | |
| 4483·10 | 4482·904 | *s, l.* | 1 | Ti. Fe. | |
| 4490·24 | 4489·911 | *s, t.* | 4 | Fe. | |
| 4492·36 | 4492·475 | *s, t.* | 0 | Cr. Fe. | |
| 4495·64 | ...... | *s.* | ... | ... | |
| 4497·72 | 4497·842 | *s.* | 0 | Ti. | |
| 4501·45 | 4501·448 | *l.* | 5 | Ti. | |
| 4508·81 | 4508·455 | *l.* | 4 | Fe. ? | |
| 4515·83 | 4515·76 | *l.* | ... | Ti. | |

*Cooke Spectrograph, Plate I.*—(continued).

| I. Calculated wave-lengths. | II. Probable wave-lengths. | III. Character of arcs. | IV. Rowland's intensity numbers for Fraunhofer lines. | V. Elements. | VI. Remarks. |
|---|---|---|---|---|---|
| 4518·64 | 4518·866 | *v.s, f.* | 0 | Ti. | |
| 4520·71 | 4520·397 | *l.* | 3 | Fe? | |
| 4522·99 | { 4522·802 | *l, t.* | 3 | ? | |
| | { 4522·974 | | 2 | Ti. | |
| 4528·50 } | 4528·798 | *s, i.d.* | 8 | Fe. } | A band. |
| 4531·64 } | 4531·123 | | 5 | Fe. } | |
| 4533·53 | 4533·419 | *l, t.* | 4 | Ti. | |
| 4541·58 | 4541·690 | *s, b.* | 2 | Cr. | |
| 4545·27 | ...... | *s, b.* | ... | ... | |
| 4548·91 | 4548·938 | *l.* | 2 | Ti. | |
| 4553·13 | ...... | *l.* | ... | ... | |
| 4555·55 | 4555·662 | *l, i.d.* | 3 | Ti. | |
| 4558·27 | 4558·28 | *s, i.d.* | ... | Ti. | |
| 4562·69 | 4562·814 | *l.* | 0 | Ti. | |
| 4570·98 | 4571·275 | *l.* | 5 | Mg. | |
| 4576·17 | 4576·512 | *v.s, i.d.* | 2 | ? | |
| 4579·83 | 4579·862 | *v.s, v.i.d.* | 00 | Ba ? | |
| 4582·96 | 4583·011 | *l.* | 1 | ? | |
| 4589·39 | ...... | *v.s, v.i.d.* | ... | ... | |
| 4600·23 | { 4600·018 | *s, i.d.* | 2 | Fe. | |
| | { 4600·279 | | 1 | Cr. | |
| 4602·23 | 4602·183 | *v.s, v.i.d.* | 3 | Fe. | |
| 4604·33 | ...... | *v.s, v.i.d.* | ... | ... | |
| 4606·32 | 4606·404 | *v.s, v.i.d.* | 2 | Ni. C. | |
| 4610·74 | ...... | *v.s, v.i.d.* | ... | ... | |
| 4612·83 | ...... | *v.s, v.i.d.* | ... | ... | |
| 4615·36 | ...... | *v.s, v i.d.* | ... | ... | |
| 4618·07 | ...... | *v.s, v.i.d.* | ... | ... | |
| 4619·83 | 4619·711 | *v.s, v.i.d.* | 1 | Cr. | |
| 4622·17 | 4622·128 | *v.s, f.* | 1 | Cr. | |
| 4625·07 | 4625·227 | *v.s.* | 5 | Fe. | |
| 4628·15 | ...... | *l.* | ... | ... | |
| 4633·25 | 4633·100 | *s, i.d.* | 4 | Fe. | Middle of a band. |
| 4637·89 | 4637·685 | *s, i.d, b.* | 5 | Fe. | Do. do. |
| 4645·27 | 4645·368 | *s.* | 0 | Ti. | |
| 4647·41 | 4647·617 | *s.* | 4 | Fe. | |
| 4650·85 | ...... | *s.* | ... | ... | |
| 4653·39 | ...... | *s.* | ... | ... | |
| 4655·82 | 4655·82 | *s.* | ... | Ti. | |
| 4662·31 | 4662·149 | *v.s, i.d.* | 1 | Fe. | Middle of a broad band. |
| 4665·89 | 4666·076 | *s.* | 1 | Cr. | |
| 4668·84 | ...... | *s.* | ... | ... | |
| 4677·88 | 4677·604 | *v.s, f.* | 00 | Ti. | |
| 4680·83 | 4680·658 | *v.s, f.* | 1 | Cr. | |
| 4690·15 | 4690·317 | *v.s, f.* | 4 | Fe. | |
| 4697·60 | ...... | *v.s, f.* | ... | ... | |
| 4701·99 | ...... | *s.* | ... | ... | |
| 4707·34 | 4707·457 | *s, b.* | 5 | Fe. | Middle of a band. |

*Cooke Spectrograph, Plate I.*—(continued).

| I. Calculated wave-lengths. | II. Probable wave-lengths. | III. Character of arcs. | IV. Rowland's intensity numbers for Fraunhofer lines. | V. Elements. | VI. Remarks. |
|---|---|---|---|---|---|
| 4713·25 | 4713·252 | *l, f.* | ... | He. | |
| 4721·01 | 4721·179 | *v.s, f.* | 2 | Fe. | |
| 4726·78 | ...... | *v.s.* | ... | ... | |
| 4730·20 | 4730·212 | *v.s.* | 2 | ? | |
| 4732·02 | 4731·984 | *v.s.* | 1 | Ni. | |
| 4735·33 | ...... | *v.s.* | ... | ... | |
| 4740·97 | ...... | *v.s, v.f.* | ... | ... | |
| 4744·38 | 4744·573 | *v.v.f, v.v.s.* | 3 | Fe. | |
| 4752·80 | 4752·613 | *v.s, v.i.d.* | 3 | Ni. | |
| 4754·97 | 4754·949 | *v.s, v.i.d.* | 1 | Ni. | |
| 4760·28 | ...... | *s, b.* | ... | ... | |
| 4765·36 | 4765·652 | ...... | 2 | ? | Middle of a band. |
| 4771·00 | 4771·279 | *s, v.f.* | 0 | Ti. Co. | |
| 4778·28 | 4778·441 | *s.* | 0 | Ti. | |
| 4782·00 | ...... | *f.* | ... | ... | |
| 4785·15 | ...... | *v.s, f.* | ... | ... | |
| 4787·88 | 4788·018 | *v.s, f.* | 1 | Fe. | |
| 4796·75 | ...... | *v.s.* | ... | ... | |
| 4803·47 | ...... | *s.* | ... | ... | |
| 4809·27 | ...... | *v s, v.f.* | ... | ... | Probably a double. |
| 4822·34 | ...... | *s.* | ... | ... | |
| 4830·96 | ...... | *v.s, v.f.* | ... | ... | |
| 4838·89 | { 4838·699 | *v.s, v.f.* | 2 | ? | |
| | { 4838·837 | | 1 | Fe. Ni. | |
| 4847·45 | 4847·497 | *v.s, v.f.* | 0 | Ca. | |
| 4853·97 | 4853·960 | *s.* | 00 | ? | |
| 4856·11 | 4856·203 | *l.* | 1 | Ti. | |
| 4860·95 | 4861·527 | *v.l, b.* | 30 | H. | |
| 4870·34 | 4870·323 | *s.* | 1 | Ti. | |
| 4876·67 | ...... | *v.s, v.f.* | ... | ... | |
| 4882·20 | 4882·336 | *s.* | 3 | Fe. | |
| 4889·92 | ...... | *s.* | ... | ... | |
| 4898·95 | ...... | *s.* | ... | ... | |
| 4909·04 | ...... | *v.s, v.f.* | ... | ... | |
| 4919·30 | 4919·174 | *s, i.d.* | 6 | Fe. | Middle of a broad band. |
| 4922·50 | 4922·446 | *l.* | 2 | Cr. | |
| 4932·83 | ...... | *l.* | ... | ... | |
| 4937·14 | ...... | *v.s, v.f.* | ... | ... | |
| 4956·01 | ...... | *s, f.* | ... | ... | |
| 4981·46 | 4981·912 ? | *v.s, v.f, b.* | 4 | Ti. | |
| 5005·56 | 5005·896 ? | *v.v.s, v.v.f.* | 4 | Fe. | |
| 5016·61 | 5016·340 | *l.* | 2 | Ti. | |
| 5168·46 | { 5167·497 | *l.* | 15 | Mg. | |
| | { 5167·678 | | 5 | Fe. | |
| | { 5169·069 | | 3 | Fe. | |
| | { 5169·220 | | 4 | Fe. | |
| 5172·96 | 5172·856 | *l.* | 20 | Mg. | |
| 5183·79 | 5183·791 | *l.* | 30 | Mg. | |

*XV.—The Spectrum of the Corona with the 6″ prismatic camera.*

Even the best exposed plate of the series gives hardly anything more than a small arc of green coronium. Happily, however, some excellent results have been secured with the other instruments, and this question will be dealt with at length in a subsequent section. Plate IV of the six-inch prismatic camera gives the wave-length of the green coronium arc equal to 5303·026, but owing to the faintness of the arc this value is not reliable to any decimal of an Angstrom unit. (See Plate IX, fig. 3.)

*XVI.—The Slit Spectrograph.*

*Description of the instrument.*—The image lens employed was an eight-inch visual lens by Sir Howard Grubb of 114 inches focus, giving an image of the sun one inch in diameter. It was mounted firmly with its tube in the meridian on two masonry pillars, and was supported on two brackets having vertical and horizontal movements for adjustment. The lens was centred by holding a thin strip of white wood at the principal focus and bringing the reflected image of the tip of the wood coincident with the tip itself when viewed along the axis of the telescope tube. No further adjustment was found necessary when the ordinary method with star images at night was subsequently tried.

A twelve-inch Foucault siderostat by T. Cooke and Sons was employed for reflecting the solar light into the image-lens. The centre of the latter was lower than that of the mirror, but was kept high enough to fill the whole of the lens with light from the siderostat; a portion of the mirror was thus available for feeding two other small prismatic cameras mentioned below.

The spectroscope was composed of a dense flint prism of 60°, having faces $5\frac{1}{8}$ inches × $3\frac{1}{8}$ inches. The collimator was intended to be a three-inch lens specially constructed for the purpose, but when it arrived in camp from England a week before the eclipse, it was found to be only twenty inches in focus instead of forty-two inches as ordered. Its employment would have reduced the effective aperture of the spectroscope to 1·5 inches; for this reason I was compelled to reject it though the time at my disposal was short, and the lens from an ordinary three-inch refractor of forty-three inches focus which was available was temporarily attached to the collimator tube by a square wooden sleeve. The slit was a highly polished one by Hilger, with only one jaw opening by a micrometer screw; its height was 2·25 inches, and this full height was employed during the eclipse. The camera lens was also three inches in diameter by Grubb, specially corrected for G. It was fitted into a square mahogany camera which carried a long vertical slide holding a focussing glass and six plates $4\frac{3}{4}$ inches × $2\frac{1}{8}$ inches. The focussing rack for the collimator was at the lens-end, while the camera was focussed by racking the slide in and out. The collimator prism and camera were all very firmly mounted on a very solid base of wooden framework and all the exposed parts were covered over with enamelled cloth. The whole spectroscope so constructed was next firmly fixed on a strong frame-work of rough teak rafters securely fixed into the ground and braced by cross pieces. The inside

of this skeleton frame of teak rafters was filled with rubble stone, and its outside was similarly packed; this gave the structure exceptional stability. The instrument, as mounted, is shown in Plate XIV, figs. 1 and 2.

The spectroscope was first adjusted visually with the region G in the centre of the field by Schuster's method, but the final adjustments were made by numerous trial photographs of the solar spectrum. The several parts of the spectroscope were not permanently screwed down till the adjustments were completed. The image of the sun was focussed on the reflecting slit also visually by bodily moving the image lens and its tube in their supports, and the final adjustment was accomplished by getting the limb of the sun sharp in the trial photographs. This was done with such precision that one of the best views of the eclipse was obtained by the observer in charge of the slit-end of the instrument by looking at the image reflected from the polished surface of the slit. Endless cords leading from the siderostat to the slit-end of the spectroscope enabled the operator in charge to place the image of the slit in the requisite position with the utmost ease and precision. A teakwood frame-work covered with canvas sheltered the spectroscope and the operator at the slide end. The trial photographs were well in focus from $\lambda$ 3900 to $\lambda$ 5500, *i.e.*, from K (Ca) to a little beyond 1474 K. The length of the spectrum from K to E was 1·45 inches, and the slit was sufficiently narrowed to show distinctly divided the faint narrow pair at $\lambda$ 4295 in Müller's map of the Solar Spectrum. (Publications of the Potsdam Observatory, Volume II, Plate 33.)

*Personnel.*—(1) Mr. H. J. Unvala, B.Sc., had charge of guiding the image on the slit and calling out to expose.

(2) Mr. B. A. Wadia (student) exposed the image lens and shut it at the call from Mr. Unvala.

(3) Mr. K. D. Sanga (student) exposed the plates at the camera-end.

*Programme of work.*—As totality was calculated to last about 120 seconds, it was arranged to begin the first exposure five seconds after second contact, in order to allow sufficient time to the operator at the slit to put the limb of the moon exactly tangential to the vertical slit. The first exposure was to be for five seconds, the second for one hundred seconds and the third up to the end of totality.

*Programme actually carried out.*—The first exposure was commenced at "115 seconds" and ended at "110 seconds"; the second exposure was commenced at "106 seconds" and ended at "5 seconds"; and the third exposure lasted from the call "1 second" to "*Flash, over.*" The plates employed were Edward's Antihalation Snapshot Isochromatic.

*Photographs secured.*—The third plate on which the exposure was practically instantaneous came out blank. The first plate only showed images of the lower stratum of the chromosphere in K, H, $H_\delta$, $H_\gamma$, *f* and $H_\beta$ radiations; of these the H and K lines are longest and thickest, while $H_\delta$ is the shortest, being a mere point.

The true coronal spectrum is altogether absent, except perhaps a trace of the continuous one. However, the second plate of one hundred seconds exposure has come out very successful and is full of interesting details. The original negative is too thin for direct reproduction, but a careful drawing made to scale from the plate by Mr. H. Cousens is reproduced on Plate XV, fig. 1. First taking the chromospheric slit images, the point which arrests attention is the breaks in the middle of H and K, which do not occur in the first plate. This is probably due to the circumstance that the slit was placed slightly inside the limb of the sun and the advancing moon cut off the chromosphere at the tangent point after the first exposure. A very slight displacement of the image on the slit is as likely to have caused the difference. The northern sections of the H and K lines are also much shorter than the southern. The thicknesses of the various layers are given by the heights of lines K, H, &c. Taking the whole height of the spectrum as 10, the H and K lines are 3·5, $H_\delta$ 1·25, $f$ and $H_\gamma$ 0·8, while $H_\alpha$ is the shortest scarcely exceeding 0·2. The explanation of the different behaviour of the three lines of hydrogen is probably to be found in the colour curve of the plate (Edward's Isochromatic) used (see fig. 6). The continuous spectrum of the corona on the southern side extends two divisions, while on the northern side it is over five divisions at the highest point. This is due to the greater extension of the corona in the northern region cut by the slit than on the southern. Of the three corona lines most distinctly seen the most intense is the middle one, the next is the one between $H_\gamma$ and $H_\delta$, while the well-known green line is the faintest;* their heights in the northern portion are 3·7, 3·5 and nearly 5 divisions respectively; the most intense line is also impressed on the whole southern portion of the continuous spectrum up to two divisions of the scale. The green line on a background of faint continuous spectrum is, moreover, *projected in the otherwise blank interval.* Remembering that the actinic intensity of the light is there much less than lower down the spectrum, it will not be rash to ascribe this behaviour of the green line to a different origin from the other two corona lines.†

Comparing the position of the maximum intensity of the continuous corona spectrum with the ordinary solar spectrum, we are at once struck by the fact that the corona intensity curve is much displaced towards the red, and are, therefore, entitled to conclude that the temperature of the source which gives the continuous spectrum

* Professor Campbell in his paper on the "Wave-lengths of the Green Coronal Line," Astrophysical Journal, Volume X, page 186-7, says that "the photographic action of the green radiation was vastly stronger than in the case of the other two lines, even though the green line lay in a region of weakness on isochromatic plates," and he attributes the failure of Newall to obtain an impression of the corona in the line at λ 4230 to this circumstance. This is in contradiction to the above results which are borne out by the experience of Captain Hills at the Eclipse (*vide* Proceedings of the Royal Society, Vol. LXIV, page 54 and plate).

† Sir Norman Lockyer, from an examination of a very extensive series of coronal rings, recorded on his Viziadurg photographs, has independently arrived at similar conclusion that "at least three substances are in question" (*vide* Proceedings of the Royal Society, Vol. LXVI, page 191).

in the corona is lower than the general temperature of the sun, as pointed out by Schuster for the Eclipse of August 1886 (*vide* T. R. S., Volume 180, page 341).

The complete absence of a Fraunhofer spectrum goes to indicate the absence, or rather the extreme weakness, of reflected sun-light in the inner corona.

The wave-lengths of the corona lines were determined by Cornu-Hartmann formula taking the means of three independent settings on each line as the true micrometer reading. The three standard wave-lengths employed were those for $H\beta$, $H\gamma$, and $H\delta$. The only possible source of error can be traced to the fact that these Hydrogen lines and the corona lines are not in the same horizon on the plate, and the assumed parallelism between the settings on the different lines is likely to introduce a systematic error in the values for the corona lines. The wave-lengths so obtained are $\lambda$ 4230·7, $\lambda$ 4566·2 and $\lambda$ 5301·195. The last was got by extrapolation, as there was no line on the plate on the red side of the coronal line. The value of the first wave-length is very nearly the same as that obtained by Sir Norman Lockyer which is $\lambda$ 4231·3. This line is without doubt the one for which the wave-length of 4233·5 nearly coincident with an iron chromospheric line was assigned by previous observers, and is most probably the same as the one whose origin is marked as "*inconnu*" with a wave-length of 423·12 by Deslandres in his report of the Eclipse of 1893. The second and the most intense line on my photograph whose wave-length I got as 4566·2 may also be the same as the one given in Deslandres' list as "unknown" at wave-length 455·6. My determination of the well-known green coronal line on *this photograph* comes out $\lambda$ 5301·195, which is nearly two Angstrom units less than those of Campbell, Fowler and Evershed.

An inspection of the following table will show how far the calculated wave-lengths can be depended upon; those marked with an asterisk being the three fiducial lines taken for obtaining the constants of the formula:—

| Element. | Calculated $\lambda$ (C). | Probable $\lambda$ (P). | P — C. |
|---|---|---|---|
| Calcium (K) ... ... ... | 3934·507 | 3933·825§ | −0·682 |
| Do. (H) ... ... ... | 3968·981 | 3968·625§ | −0·356 |
| * Hydrogen ($H\delta$) ... ... ... | 4102·000 | 4102·000§ | 0·0 |
| Coronal ... ... ... | 4230·708 | 4231·3† | +0·6 |
| * Hydrogen ($H\gamma$) ... ... ... | 4340·634 | 4340·634§ | 0·0 |
| Helium ($f$) ... ... ... | 4471·623 | 4471·646‡ | +0·023 |
| Coronal... ... ... ... | 4566·228 | 4568·5† | +2·3 |
| * Hydrogen ($H\beta$) ... ... ... | 4861·527 | 4861·527§ | 0·0 |
| Coronal ... ... ... | 5301·195 | 5303·7† | +2·5 |

§ Rowland. † Lockyer. ‡ Runge and Paschen.

The nearly concordant results obtained for K, H and $f$ and the much greater divergence of the values for the coronal lines tend to show that the discrepancies in the latter case are mainly due to the inherent difficulty in measuring lines in two different horizons on a very small scale photograph.

*XVII.—Two-prism spar and quartz prismatic camera.*

This instrument was essentially an improvised one. The originally intended programme was unfortunately not carried out in its entirety owing to some mistakes on the part of the operator; notwithstanding this the results obtained with it, as will be seen, are valuable.

*Description of the instrument.*—The lens, a single one of quartz three inches in diameter and of twenty-two inches focus, was stopped down to one inch by a card-board diaphragm. In front of it two spar prisms 60° each of $1\frac{1}{2}$ inch × $1\frac{1}{4}$ inch face cut in a plane perpendicular to the optic axis of the crystal were fixed upon a wooden support. The deviation of the combination was nearly 90° and the spectra obtained were nearly four inches long from $D_3$ to the extreme ultra-violet, the distance between $H_\beta$ to K being 1·2 inch. The solar image as given by the chromospheric rings in K and H was 0·22 inch in diameter.

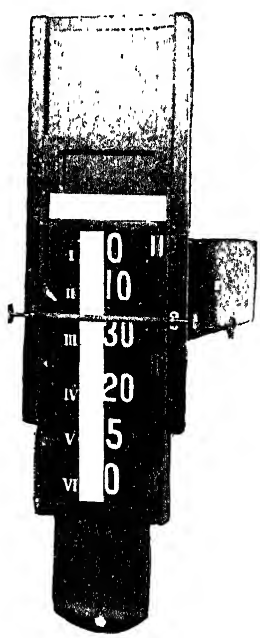


*Fig. 8: Two-prism spar and quartz prismatic camera with slide.*

The focussing glass and six plates $4\frac{3}{4}$ inches × $2\frac{1}{6}$ inches were carried in a long slide which opened automatically on being raised to the position of first exposure by a projecting spring clip on the sliding shutter coming in contact with the bottom edge of the camera and was held in position by a spring detent at the side; subsequent exposures were made by pushing back the detent and raising the slide till the detent caught into the next following notch. The camera was fixed on a wooden frame let into the ground and strengthened with boulders on the same general plan as that used with the slit spectroscope. It was placed to the west of the latter instrument so as to catch the light from the upper unused portion of the solar beam from the siderostat. Owing to its angular deviation of 90°, the instrument and the operator were altogether out of the way of the slit spectroscope (see Plate XIV, fig. 1). For focussing the instrument an eight-inch Newtonian mirror was used as the collimator, the eye-piece having been replaced by a slit and the jaws brought into sharp focus with a Ramsden eye-piece fitted on to a slide resting on the surface of the slit through which a star was simultaneously observed, which insured parallelism of the rays from the slit into the mirror when used as a collimator.

*Personnel.*—Professor G. M. Woodrow, F.L.S., of the College of Science, Poona, was in charge of the instrument and manipulated the slide.

Mr. A. B. Vaidya acted as recorder.

Mr. D. G. Dani (student) exposed and shut off the light from the camera with a card-board screen at given signals from Mr. Woodrow.

*Programme.*—The plates employed were Edward's Snapshot Isochromatic backed with antihalation composition and the proposed programme of work was as follows:—

Plate I.—Instantaneous for "flash."

Plate II.—10 seconds.

Plate III.—30 seconds.

Plate IV.—20 seconds.

Plate V.—5 seconds.

Plate VI.—Instantaneous for "flash."

Unfortunately before totality the slide was accidentally pushed up with some force and was thus automatically opened and exposed through the first two plates and a part of the third; it seems to have been immediately withdrawn and replaced in the normal position and the following programme was gone through:—

Exposure I, instantaneous, at the call "117 seconds" instead of "Flash," *i.e.* four seconds late.

Exposure II from "112 seconds" to "102 seconds."

Exposure III from "97 seconds" to "67 seconds."

Exposure IV from "61 seconds" to "40 seconds."

Exposure V from "36 seconds" to "31 seconds."

Exposure VI, instantaneous, but four seconds after the end of totality instead of at the call "*Flash, over.*"

No intimation of the premature exposure of the plates was given and on development the first two plates came out quite blackened. In the feeble light necessary for working with isochromatic plates no details were visible during development; the third plate, however, on development curiously enough blackened only through about a third of its breadth; this was also rejected, but it led to an indication of some error in exposure and not to any defect in the camera itself. The three remaining plates developed quite correctly. On examining the plates after fixing, broad Fraunhofer lines, and not arcs of H and K, together with some fainter ones were seen impressed on Plates 1 and 2. Numerous Fraunhofer *arcs* were visible on the third plate which must have got impressed during the temporary stoppage of the slide in its premature upward career. This plate (No. 3) in the subsequent operations during totality was re-exposed for 30 seconds, and on it a faint impression of the coronal spectrum in the middle of the plate which had escaped first exposure is just visible. Had I been aware of the accident, and not withdrawn the plate from the developing solution on the appearance of the black patch on a portion of it, there is no doubt that on further development this plate would have, owing to its longer exposure, given even a better impression of the corona spectrum than either Plate 4 or 5.

Of the plates (Nos. 4 and 5) on which the corona spectrum has been successfully impressed, Plate No. 4 is by far the better. It was exposed very nearly at mid-eclipse and the chromospheric circles in H and K give almost complete images of the chromosphere (see Plate XV, fig. 2). Several prominences, nine in all, are also seen. Prominence No. 1 in the south-east quadrant is impressed in the largest number of monochromatic images. A continuous streak runs parallel to this prominence through the whole length of the spectrum. In some parts it can be easily seen broken up into numerous discreet points.

The following table gives a comparative list of the monochromatic images belonging to each of the nine prominences:—

| Wave-length. | Element. | Prominence I. | Prominence II. | Prominence III. | Prominence IV. | Prominence V. | Prominence VI. | Prominence VII. | Prominence VIII. | Prominence IX. |
|---|---|---|---|---|---|---|---|---|---|---|
| 3349·04<br>3349·13<br>3349·21 | Ti | × | ... | ... | ... | ... | ... | ... | ... | ... |
| 3364·4± | Co? Ni? | × | ... | ... | ... | ... | ... | ... | | ... |
| 3374·5 | Ti | × | ... | ... | ... | ... | ... | ... | ... | ... |
| 3685·3 | Ti | × | ... | ... | ... | ... | ... | ... | ... | ... |
| 3721·8 | Hμ | × | ... | ... | ... | ... | ... | ... | ... | .. |
| 3734·1 | Hλ | × | ... | ... | . | ... | ... | ... | ... | ... |
| 3750·1 | Hκ | × | ... | ... | ... | ... | ... | ... | ... | ... |
| 3759·5 | Ti | × | ... | ... | ... | ... | ... | ... | ... | ... |
| 3798·0 | Hθ | × | ... | ... | .. | ... | .. | ... | ... | ... |
| 3835·6 | Hη | × | ... | ... | × | × | × | × | ... | ... |
| 3839·1 | Hζ | × | ... | ... | × | × | × | × | ... | ... |
| 3933·8 | Ca | × | × | × | × | × | × | × | × | × |
| 3968·6 | Ca | × | × | × | × | × | × | × | × | × |
| 4102·0 | Hδ | × | ... | ... | ... | .. | ... | ... | ... | ... |
| 4340·6 | Hλ | × | ... | ... | × | × | × | × | × | ... |
| 4471·6 | He | × | ... | ... | ... | .. | ... | ... | ... | ... |
| 4861·5 | Hβ | × | ... | ... | × | × | × | × | × | ... |
| 5875·87 | He | × | .. | ... | ... | .. | ... | ... | ... | ... |

• The continuous spectrum of the corona is most intense between F and G, where it reaches a height of nearly 0·44 of a solar diameter, equivalent to over 14′ of arc. The broad ill-defined ring a little more refrangible than $D_3$ has its origin in the continuous spectrum of the corona acting on the isochromatic plate, which has a maximum of sensitiveness for that portion of the spectrum as evidenced by the greater height to which the photographic impression has reached there than in the neighbouring parts. This has already been demonstrated by Sir Norman Lockyer regarding similar appearances in the coronal spectrum photographs of the Eclipse of April 1893. (*Vide* P. T. (A), Volume 187, page 590.)

Three coronal rings are shown on the photograph. The first is of course the well-known one in the green. It is not complete, only the eastern half being discernible. This is due to the other half being masked by the strong light of the continuous coronal spectrum falling on the same part of the plate owing to the moderate dispersion of the apparatus. The other two rings are in the extreme ultra-violet at wave-lengths λ 339 μμ and λ 346 μμ, the second being the more intense. These rings are nearly complete, but owing to the want of sharp focus they give the contour of the "coronium" distribution in a somewhat distorted form. The rings are very irregular in form, the thickness of "coronium" matter being concentrated near the solar equator. They seem to have no connection with the prominences except in the case of prominence No. 1, which seems to be situated in the same horizon as a mass of coronium; no connection moreover can be traced between these loci of concentrated coronium matter and the directly photographed "inner corona" or the extended streamers. Each of the coronium masses has at the same time produced a streak of continuous spectrum stronger than the general spectrum and three such streaks are easily recognised.

The wave-length of the green coronal line comes out λ 5303·5, being practically the same as the South Kensington value of λ 5303·7 (P. R. S., Vol. 64, p. 170) and of Campbell λ 5303·26 (A. P. J., Vol. 10, p. 190).

The problem of determining the wave-lengths of the two ultra-violet rings proved to be one of some difficulty. The rings and indeed the whole spectrum is ill-defined. There is scarcely any doubt that the camera was considerably disturbed and the swing-back moved from its original position in the hurry of resetting the slide after the premature exposure of the first three plates, and hence the want of good definition, because the same instrument has subsequently given extremely sharp spectra of sunlight with a quartz-spar collimator. Moreover, as there were no well-recognized prominence radiations beyond the corona rings in the ultra-violet, it was found necessary to employ extra-polation. The Cornu-Hartmann formula was, therefore, tested for its applicability to extra-polation. Ten prominent lines on a solar spectrogram taken with the six-inch prismatic camera were selected; they were measured with an ordinary engineer's scale, and taking the three lines $b_1$ (518·4), F (466·8) and λ 438·4 as fiducial lines, the wave-lengths of the rest of the lines were evaluated. The values came out well, as will be seen from the following table:—

| Calculated λ. | Correct λ. |
|---|---|
| * 518·4 | 518·4 |
| 485·9 | 486·1 |
| * 466·8 | 466·8 |
| * 438·4 | 438·4 |
| 434·0 | 434·0 |
| 422·7 | 422·7 |
| 414·4 | 414·4 |
| 404·6 | 404·6 |
| 396·9 | 396·9 |
| 393·4 | 393·4 |

The results proved so encouraging that a fresh determination was made with more exact readings and more correct values for the wave-lengths. The resulting values are given below:—

| Calculated λ. | Correct λ. |
|---|---|
| * 5183·79 | 5183·79 |
| 4862·27 | 4861·53 |
| * 4667·63 | 4667·63 |
| * 4383·72 | 4383·72 |
| 4340·26 | 4340·63 |
| 4226·53 | 4226·90 |
| 4045·32 | 4045·97 |
| 3961·41 | 3961·67 |
| 3944·37 | 3944·16 |

The source of the discrepancies in the decimal of a unit in the second series of determinations is to be sought for in the difficulty of dividing the selected lines, most of which were in the test photograph of the solar spectrum considerably broad compared to the thickness of the cross-wires. For instance, five divisions of the micrometer head which would not have made a very decided difference in the bisection of line $\lambda$ 4861·53 would have given the correct value. As with the lines extra-polated the differences between the calculated and correct values are less than for this line which falls within the three fiducial lines, the discrepancies must be attributed to the want of exact bisection of the spectrum lines. I have not thought it necessary to put the formula to a further rigorous test, as for my particular purpose the degree of accuracy attained was more than was possible to obtain with the coronium spectrum owing to the very undefined character of the ultra-violet rings.

For these reasons the Cornu-Hartmann formula was with confidence employed for extra-polation, and had it not been for the diffuseness and faintness of the images of the coronal rings their wave-lengths could have been determined with great exactness. The extra-polation gave the values $\lambda$ 3391 and $\lambda$ 3456, but after a very careful consideration I am not inclined to assign them more accurate values than $\lambda$ 339 $\mu\mu$ and $\lambda$ 346 $\mu\mu$. I may here state that Mr. Evershed informs me that he has detected on his Indian photographs a coronal ring at $\lambda$ 3388 ± and M. Deslandres is also reported to have observed two ultra-violet coronal rings at the following eclipse of 28th May 1900 (Astrophysical Journal, Vol. XII, page 288).

## *XVIII.—The Flash Spectrum.*

The spectrum of the Flash taken at the end of totality, four seconds after third contact, is crossed by five streaks of continuous spectrum due to the reappearing solar crescent. Numerous chromospheric arcs are recorded. The photographic action ends at about $\lambda$ 3278·0. The Hydrogen series is recorded up to $H\lambda$ and among the other more prominent radiations are those of Ca, Ti and Fe. The following table gives the wave-lengths and origins of these arcs :—

| Wave-length. | Element. | Wave-length. | Element. | Wave-length. | Element. |
|---|---|---|---|---|---|
| 3277·0 | Photo action ends. | 3457·2 | Fe. | 3835·6 $H_\eta$ | H. |
| 3338·6 | Fe. | 3472·7 | Ni. | 3889·3 $H_\zeta$ | H. |
| 3346·9 | Ti. | 3495·4 } ? | Fe. | 3933·8 | Ca |
| 3357·4 | Zr. | 3495·8 } | Ti. | 3968·6 | Ca. |
| 3370·5 } ? | Ti. | 3685·3 ? | Ti. | 4077·9 | Sr. |
| 3370·9 } | Fe. | 3707·7 | Ti. | 4102·0 $H_\delta$ | H. |
| 3380·4 } ? | Ti. | 3720·1 | Fe. | 4340·6 $H_\gamma$ | H. |
| 3380·7 } | Ni. | 3734·1 $H_\lambda$ | H. | 4471·6 | He. |
| 3404·4 } | Fe. | 3750·1 $H_\kappa$ | H. | 4861·5 $H_\beta$ | H. |
| 3404·5 } | Fe. | 3759·4 | Ti. | 4920·7 | Fe. |
| 3418·6 | Fe. | 3770·7 $H_\iota$ | H. | 5167·5 | Mg. |
| 3433·4 | Cr. | 3797·9 $H_\theta$ | H. | 5172·8 | Mg. |
| | | | | 5834·0 | Photo action ends. |

*XIX.—Single-prism spar and quartz prismatic camera.*

This consisted of a quartz-calcite achromatic lens $2\frac{1}{2}$ inches in diameter of 17 inches focus by Hilger and a spar prism of 40° with faces $2\frac{3}{8}$ in. × $1\frac{3}{4}$ in., giving a double image. Only the "ordinary" spectrum was photographed, the "extraordinary" being deflected towards the side of the camera. At the back of the camera was a slit $\frac{1}{2}$ inch broad and a double *carte de visite* slide was employed to carry Edward's Snapshot Isochromatic plates. Equi-distant marks were made on the slide and it was brought in position for each exposure by making the successive marks coincident with an index mark on the camera and there kept in position by a thumb screw pressing against the slide. The camera was placed to the east of the image lens of the slit spectroscope and received light from the upper portion of the siderostat mirror (see Plate XIV, fig. 2). The length of the spectrum obtained was $\frac{7}{8}$ inch, the distance between $H_\beta$ and K being $\frac{1}{4}$ inch.

*Personnel.*—(1) Mr. S. D. Writer, Drawing Master of the College of Science, Poona, was in charge of the instrument and manipulated the slide; (2) Mr. J. D. Dubash (student) exposed and shut off the light from the camera with a card-board screen at a call from Mr. Writer; and (3) Mr. H. D. Mistri (student) acted as recorder.

*Programme.*

| Exposure. | Duration. | Times of actual exposures at the call of |
|---|---|---|
| I ... | Instantaneous ... | 116 seconds. |
| II ... | Instantaneous ... | 114 seconds. |
| III ... | 1 second ... | 113-112 seconds. |
| IV ... | 5 seconds ... | 84-80 seconds. |
| V ... | 10 seconds ... | 75-65 seconds. |
| VI ... | 15 seconds ... | 63-47 seconds. |
| VII ... | 10 seconds ... | 10-0 seconds. |
| VIII ... | Instantaneous at the end of totality. | One second after totality was over. |

It will be observed that the first exposure was made fully five seconds after the appointed time and during the one second exposure the plate was somehow shifted, so that there are two impressions of the chromospheric arcs one below the other instead of one. The last (eighth) exposure was also evidently a good deal after the end of totality as no less than five streaks of continuous spectrum due to the reappearing solar crescent behind the rugged edge of the moon are photographed along with the chromospheric spectrum.

Plate I only gives the principal chromospheric arcs and there is no particular feature calling for special remarks.

Plate II, exposed seven seconds after totality, gives the first indication of the green corona ring along with numerous chromospheric arcs which are still persistent.

Plate III, exposed eight seconds after totality, has a fully developed and complete green ring of coronium, and there are strong indications of another ring on it. The chromospheric arcs are also present.

Plate IV, exposed thirty-six seconds after totality, has the chromospheric arcs completely absent. Prominence No. 1 has, however, left numerous impressions, and the other prominences are shown in radiations H and K.

Plate V, which was partially spoilt during development, shows no special features of interest.

Plate VI, exposed fifty-seven seconds after totality, has in addition to a well impressed green coronium ring indications of three other rings, one of them being in the ultra-violet.

Plate VII, taken during the last ten seconds of totality, has numerous chromospheric arcs besides a complete ring of green coronium on a continuous spectrum and shows more chromospheric lines than Plate VIII, presumably taken at the end of totality but evidently exposed several seconds afterwards.

The chromospheric arcs recorded are given in the following table :—

| Wave-lengths. | Element. | Wave-lengths. | Element. | Wave-lengths. | Element. |
|---|---|---|---|---|---|
| 3346·9 | Ti. | 3720·1 | Fe. | 4077·9 | Sr. |
| 3354·8? | Ti. | 3734·1 H$\lambda$ | H. | 4102·0 H$\delta$ | H. |
| 3368·2 | Cr. | 3750·15 H$\kappa$ | H. | 4134·01 } ? | Fe. |
| 3377·6 } | Ti. | 3759·4 | Ti. | 4134·49 } | |
| 3377·7 } | | 3770·8 H$\iota$ | H. | 4152·1 | Fe. |
| 3389·8 | Fe. | 3797·9 H$\theta$ | H. | 4215·7 | Sr. |
| 3399·8 | ? | 3835·6 H$\eta$ | H. | 4340·6 H$\gamma$ | H. |
| 3413·3 | Fe. | 3858·3 | Ti. | 4401·18 | ? |
| 3423·8 | Ni. | 3874·2 | ? | 4471·6 | He. |
| 3445·9 | Fe. | 3889·3 H$\zeta$ | H. | 4861·5 H$\beta$ | H. |
| 3685·3 | Ti. | 3933·8 | Ca. | 4920·7 | Fe. |
| 3703·9 H$\xi$ | H. | 3968·6 | Ca. | 4950·3 | Fe. |
| 3711·9 H$\nu$ | H. | 4013·0 | Ti. ? | 5875·8 $D_3$ | He. |

## *XX.—The integrating spectrograph.*

The fifth spectrograph employed was an integrating one. The importance of examining the light of the eclipsed sun with an integrating spectroscope cannot be better summed up than in the following words of Sir Norman Lockyer :—" In organizing the work for the eclipse of 1871, stress was laid on the importance of obtaining a photograph of *all* the light radiated earthwards during an eclipse, to

supplement the work of the slit spectroscopes which had to do with the light radiated by special parts of the solar surroundings. This work is a thousand times more important now that the spectrum of the prominences is so clearly separated from that of the corona by the prismatic cameras, because it enables us to make a flank attack, so to speak, on the corona spectrum."*

It was for these reasons deemed advisable to attack the problem also from this direction. The instrument was composed of a collimator $1\frac{1}{2}$ inches in diameter of 46 inches focus which embraced a field of nearly 2° in diameter, with two prisms, one a Rutherford compound prism $1\frac{1}{2}'' \times 1\frac{1}{4}''$ face and $3\frac{1}{4}''$ at the longer base and another a single 60° prism $2\frac{1}{8}'' \times 1\frac{1}{4}''$. The camera lens was a Dallmeyer Rapid Rectilinear of $1\frac{3}{4}''$ diameter and 13″ focus.

The slit was kept at such a width that when directed to the cloudless sky at approximately the same altitude as the sun at the time of the eclipse it gave a fully developed image of the sky spectrum in five seconds. The spectroscope was mounted on an equatorial stand driven by hand and was guided by a small finder, the eye-piece of which was provided with a ring micrometer which exactly covered the circumference of the sun. The instrument was, therefore, directed and maintained in the correct position with very great ease. The instrument as erected is shown in Plate XVI, figs. 1 and 2.

*Personnel.*—Mr. D. D. Sanga, Lecturer in Veterinary at the College of Science, Poona, was in charge of the instrument and drove it with the help of the finder. Mr. F. S. Bharucha (student) opened the slide and closed it at the appointed time and Mr. H. A. Lilamvala (student) uncovered and covered the slit at the other end.

The exposure was commenced at five seconds after commencement of totality and was continued up to five seconds before the end of totality. A total exposure of 110 seconds was therefore given, but on development the plate came out blank. The failure in obtaining any impression is inexplicable, except on the supposition that the total light of the corona was very much less than one twenty-second part of the light reflected from an equal unclouded area of noon-day sky in India; for there is not the slightest doubt that the slide was correctly opened, the slit exposed and the instrument carefully directed and kept on the eclipsed sun as arranged for. This failure is more significant, as Sir Norman Lockyer with a larger instrument was unable to get the integrated spectrum at Viziadurg on the same occasion.

This form of the spectroscope is eminently suited for giving decided information regarding the comparative *total* intensities of the different radiations composing coronal light, and a more systematic attempt at some future eclipse with full preliminary trials on the possible total actinic intensity of the corona seems to be highly desirable.

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* Lockyer's Recent and Coming Eclipses, 1897, pp. 21-22.

### *XXI.—The Coronal spectrum.*

We may here pause to inquire what light our observations throw on the nature of the corona spectrum.

The spectrum is no doubt composed of at least three components: (1) a continuous spectrum due to incandescent meteoric (?) dust, (2) a gaseous spectrum due to one or more unknown elements in the state of gas, (3) a true Fraunhofer spectrum due to light directly reflected from the sun on the coronal matter. It is quite easy to conceive that the spectrum from such a composite source should vary. The intensities of the first and second sources would depend on the general state of solar activity, while the third would depend on the relative reflecting power of the first.

A systematic investigation of the problem may be said to have commenced with the observations of Rayet in 1868. Discordances in subsequent observations have strengthened the belief in the variability of the spectrum and more than one investigator have thrown out the suggestion, which has now practically received universal acceptance, that the variability goes hand in hand with the sun-spot cycle.

I have collected here the most important spectroscopic observations since 1868, indicating at the same time for the epoch of each eclipse the mean solar spot activity in Wolf's frequency-numbers both for the month and for the year of occurrence.

#### *Previous observations of the spectrum of the Corona.*

**1868.**
Monthly number = 4·9
Mean annual number = 7·3

*Rayet*: Lines F, E (1474 K) and D ($D_3$) traced to a height of 6′ above sun's limb when the great prominence according to DeLa Rue was 3′ 22″ high.

*Rhia, Tennant and Pogson*: continuous spectrum only.

**1869.**
Monthly number = 68·2
Mean annual number = 66·3

*Harkness*: Corona spectrum continuous and as bright as that of the full moon; one bright line.

*Young*: Faint continuous spectrum with one bright line (1474 K). This line persisted in other parts besides prominence regions.

*Pickering*: A continuous spectrum with two or three bright lines, the brightest being 1474 K.

**1870.**
Monthly number = 130
Mean annual number = 139·1.

*Young*: Line 1474 K traced from 10′ to 13′ from the sun; it extended E and W further than towards the poles; no dark lines though carefully looked for.

*Carpmeal*: Three bright lines, of which 1474 K was 8′ above sun's limb.

*Harkness*: Line 1474 K estimated as extending 10′ to 15′ above sun's limb. Two less refrangible lines were suspected.

*Winlock* observed C, $D_3$, 1474 K and F. Line 1474 K was seen to a distance of 25′ above sun's limb and the others nearly as far. No dark lines were seen though carefully looked for.

*Burton, DeSoza and Lorenzi* observed 1474 K.

*Nobile* saw 1474 K for 15 seconds after end of totality.

*MacLear* saw five bright lines.

1871.
Monthly number = 105·4.
Mean annual number = 111·2.

*Resphigi* saw three rings corresponding to C, 1474K and F. The second was the brightest, while the last was the faintest. The green line was 6′ to 7′ high, while C and F were nearly the same.

*Lockyer* saw three Hydrogen rings together with 1474K ring, all about 2′ wide; 1474K was the faintest. With a slit spectroscope 1474K was about 6′ above sun's limb; continuous spectrum and Hydrogen lines being very bright.

*Herschel and Tennant* saw 1474K 10′ from the limb.

*Saxton and Tupmam* saw 1474K.

*Fyers* saw C, $D_3$, 1474K and F.

*Ferguson* saw same as Fyers and four other lines in addition.

*Janssen* noted Hydrogen and 1474K to a distance of 10′ to 12′ from the limb. Besides these D was seen *dark* and also some other faint ones in the green.

*Moseley* traced 1474K about 22′ from limb.

1874.
Monthly number = 32
Mean annual number = 44·6

*Stone.*—Spectrum of inner corona (7′ from limb) gave the Hydrogen lines, 1474 K and two or more much fainter lines near 1474 K of less refrangibility. A continuous spectrum background but no dark lines. In the outer corona up to 45′ from limb he saw 1474 K bright and a faint Fraunhofer spectrum.

1875.
Monthly number = 29·1
Mean annual number = 17·1

*Schuster*: Photography was for the first time employed for the spectroscopic examination of the corona. The attempt was very partially successful. One corona ring was identified with Hydrogen and a continuous spectrum was impressed on the plate.

1878.
Monthly number = 0·1
Mean annual number = 3·4

The observations of this eclipse are very conflicting, but the observers agree in concluding that the gaseous corona radiation was very weak.

*Barker* saw a very bright continuous spectrum with Fraunhofer lines, which was relatively brighter than that of the moon giving dark lines of the same intensity. He, therefore, concluded that the corona consisted of reflected sun light mixed with incandescent meteoric matter.

*Schuster* saw a very bright continuous spectrum and suspected *two* green lines, but he did not notice any dark lines.

*Rees* saw continuous spectrum with Fraunhofer lines.

*Sampson, Newcomb and Clark* saw only a continuous spectrum.

*Lockyer and Harkness* did not notice any green line or ring.

*Draper* photographed a continuous spectrum without trace of any rings; visual observations were equally negative.

*Young*, on the other hand, saw C, $D_3$, 1474 K and F bright. C was traced to 10′ and F to 5′ from the limb.

*Bennet* saw both 1474K and F.

*Seagrave* saw one faint line.

*Eastman* traced 1474K to a distance of 14′ from the moon's limb besides observing the bright continuous spectrum. He concluded that the green line belonged to the inner corona.

**1882.**
Monthly number = 64·1
Mean annual number = 59·6

*Thollon* observed C, $D_3$, 1474K, F and a group of rays in the violet (photographed by Schuster) 10′ to 15′ from the moon's limb. He distinctly observed 1474K on a bright continuous spectrum.

*Trepid,* who confined himself to the neighbourhood of the green corona line, observed it on a blank background and determined its position as exactly coinciding with the more [illegible] component of the solar 1474K pair.

*Puiseux* saw in the coronal spectrum C, $D_3$, 1474K, two lines of the group *b* and a line between 1474K and E. He did not see any continuous spectrum.

*Tacchini* observed the coronal spectrum to about 7′ from the moon's limb. He also noted in the red part of the spectrum the lines 6489, 6491, 6494 and 6498 of which the last reached the greatest height from the moon's limb.

*Abney* and *Schuster* noted K and H (Calcium) $H_\alpha$, $H_\beta$, $H_\gamma$ and $H_\delta$ corona rings also a faint $D_3$ ring. Continuous spectrum of the N side was recorded up to λ 3490, and near G the continuous spectrum was traced up to 1·47 times the radius of the sun.

Corona lines, one less refrangible than G, another a little less refrangible than H, also two or three in ultra-violet, were noted. Also Fraunhofer dark lines about G were clearly [illegible]. A list of other lines, about thirty, seen in the coronal spectrum is given on page 270, P. T. R. S. for 1884.

**1883.**
Monthly number ... = 32·1
Mean annual number... = 63·7

*Hastings* saw 1474 K at second contact 10′ to 12′ high; also bright continuous spectrum, but with only two lines, the bright 1474K coronium and dark Fraunhofer D (not $D_3$). 1474 K was observed up to 15′ from limb.

*Upton* at the beginning of totality saw C, $D_3$, 1474 K and F bright. One hundred seconds after totality began coronal rings C, $D_3$, 1474K supplanted the lines; nothing is said about F. C and $D_3$ rings were twice as thick as 1474K, C being brightest.

*Brown* saw during totality only 1474K intensely bright. It increased [illegible] in brilliancy while the continuous spectrum grew fainter. He also observed a faint dark line in orange-red.

*Janssen* : The base of the coronal spectrum was a complete Fraunhofer [illegible]. The principal solar rays, D, B, E and C were among them. Respighi's ring (*f*) was not concentric with the limb of the moon and the coronal light had no important proportion of solar light.

**1886.**
Monthly number = 16·9
Mean annual number = 25·4

*Schuster* and *Darwin* : Continuous spectrum from λ 4950 to λ 3700. The maximum of actinic intensity was more towards the red end than with solar light. This shows that the continuous spectrum was [illegible] due to incandescent matter of a lower temperature than that of the sun. Fraunhofer lines were present though faint. The [illegible] of the northern hemisphere was weaker than of the southern. At least twelve lines were [illegible] to corona proper.

**Jan. 1889.**
Monthly number = 0·8
Mean annual number = 6·3

*Keeler* noted a bright continuous spectrum; also dark Fraunhofer lines, but faint; they were not so intense as in the sky [illegible]. 1474K was bright up to 12′.

1893.
Monthly number = 88·1
Mean annual number = 84·9

*Hills* photographed 47 lines in the corona spectrum; most of these are very likely chromospheric.

*Baume Pluvinel* recorded a Fraunhofer spectrum.

*Fowler* noted 1474 K and seven other lines.

*Deslandres* photographed numerous lines which he ascribed to the corona.

1896.
Monthly number = 27·2
Mean annual number = 41·8

*Shackleton* photographed several rings and a continuous spectrum.

A glance at these observations shows that the bright line spectrum distinctly varies with solar activity. It is not so easy to arrive at any result regarding the continuous spectrum as the photometric measurements of its intensity have not been seriously attempted. The Fraunhofer spectrum seems also to undergo changes.*

The present eclipse, though it occurred near the time of minimum, happened at a period of actual abnormal activity, and the evidence of the Jeur photographs is all tending to show that the bright line spectrum was not feeble and my eye-observations and those of the Reverend Father Haan recorded in a subsequent section confirm this. The continuous spectrum in the quartz camera reached the height of nearly 0·45 of a solar diameter. On the other hand, the slit spectroscope did not give any indications of a Fraunhofer spectrum.

The principal radiations of the gaseous coronal spectrum from a combination of the several photographs are proved to be at wave-lengths :—

$\lambda$ 5303·7
$\lambda$ 4568·5
$\lambda$ 4231·3
$\lambda$ 3456·±
$\lambda$ 3390·±

The ordinary prominence lines of Hydrogen, Helium and Calcium do not seem to form part of the true coronal radiation.

## XXII.—*Visual spectroscopic observations.*

Three instruments were employed for the purpose, viz., a "binocular spectroscope," an objective prism telescope, and an analysing slitless spectroscope.

### (1) *The binocular spectroscope.*

This instrument consisted of a two-inch binocular, in the right-hand eye-piece of which a powerful direct vision prism of Jena glass was inserted. The prism could be rotated so as to bring the dispersion parallel with the motion of the moon. The front of each object glass was provided with two moveable dark glasses of graduated tints.

The instrument was employed by me principally for noting the moments at which the two "flashes" occurred. I had also intended to study the distribution of

* With reference to this last point *cf.* Ast. Phy. Journal, Vol. XIV, page 355. (Note Feb. 1902.)

the green coronium gas in relation to the visible corona. Some twelve minutes before totality I could with difficulty discard one of the dark glasses from front of the spectroscope and ten minutes and a half before totality dark Fraunhofer lines began to appear, which rapidly increased and multiplied until a minute and twenty seconds before totality bright chromospheric arcs began to make their appearance. The second dark glass was then removed. The first chromospheric arcs to be seen were those of $D_3$, E, F and G, after which the rapidly disappearing edge of the sun became broken up into numerous fine bright horizontal lines which snapped almost simultaneously with the flashing out of the bright line spectrum. The "flash" had occurred at 12h. 19m. 36s. Madras Mean Time. I at once gave the pre-arranged signal "*Flash*" and a second afterwards "*Totality*." I next glanced at the chromospheric arcs and prominences: these had practically the same form in Helium and Hydrogen radiations. Next I directed my attention to the green coronium arc. I was very much surprised not to be able to pick it out; on the contrary, I found the whole spectrum suffused with strong prismatic colours in which the green predominated. It was after great difficulty that I could notice the green coronium arc which was very broad and diffuse; the continuous spectrum of the corona had practically drowned it in its powerful light. Next I attempted to compare the corona as seen directly through the opera glass with its green image in the spectroscope, but I failed to see the former. I could not understand what had happened and I gave up the attempt when bright chromospheric arcs had begun to appear in the opposite quadrant; then came the second flash, more suddenly, it seemed, than the first, and all was over. The time from "flash" to "flash" was exactly 120 seconds. Before I determined to give up the attempt to view the corona through the opera-glass one hundred seconds of totality had passed, and as it was important to catch the second flash I had to suppress the great desire to have a direct eye-view of the eclipse. After totality I found that the set of dark glasses in front of the left-hand object glass had not been removed, in fact I had completely lost sight of their existence; and hence of the "incomparable corona" I had seen nothing.

The instrument had completely fulfilled its task of noting the moments when the two contacts occurred, but for examining in detail the distribution of the green coronium gas it was not powerful enough; much higher dispersion, it seems, is absolutely necessary for the purpose.

### (2) *The objective-prism telescope.*

This was a three-prism spectroscope by Browning without its collimator. It was mounted on a parallactic stand. The Reverend Dr. D. Mackichan, M.A., D.D., LL.D., Principal of Wilson College, Bombay, was entrusted with the instrument. He concentrated his attention to the observation of the "1474 K" arc; it was distinctly seen of crescent shape during the first half of totality, but Dr. Mackichan failed to decern any remarkable peculiarities about it. (See Plate XVI, fig. 1.)

### (3) *The slitless analysing spectroscope.*

The Reverend Father F. X. Haan, S.J., Professor of Physics at St. Xavier's College, Bombay, had charge of this spectroscope. His interesting report is given below *in extenso* :—

"The instrument used was a Stewart's 3-inch telescope, combined with a Hoffmann's direct-vision spectroscope with 5 prisms, dispersion 12°, mounted equatorially. The eye-piece of the telescope being removed, and likewise the slit of the spectroscope, the instruments were joined together by a strong brass tube and the image of the sun was focussed to where the slit had been. The position of the spectroscope was such that the direction of the movement of the moon was perpendicular to the edge of the prisms. The part of the spectrum from the line D to the line F could be seen at the same time. At the beginning of observation a smoked glass was used, which was removed when totality set in.

"Ten minutes before totality the light had considerably diminished, and the country presented the same aspect as when it is observed through a glass of neutral tint; nothing was to be seen of a pale yellow colour; also at the horizon the sky kept its neutral colour; after totality this neutral tint was not perceptible.

"At 1h. 15m. 39s. M. M. T. the dark lines E, *b* and F appeared. At 1h. 17m. 29s. all the dark lines of the spectrum were distinctly visible. About half a minute before totality the spectrum, which up to this had the same diameter as the disk of the sun, began to shrink, and at this moment the lines $D_3$ and F began to reverse. The part of the line F in the middle of the continuous spectrum remained dark; but the rim and its projecting parts were bright; the line $D_3$ was at the beginning not visible in the continuous spectrum, but became afterwards luminous throughout. These two arcs of $D_3$ and F kept always the same extension.

"When the continuous spectrum had nearly three-fourths of its original breadth, other lines began to reverse, but not as high as $D_3$ and F. When reduced to one-fourth, most of the dark lines of the spectrum were reversed; but they were not all of the same height, and some of them were very short. E and *b* had at this moment about half the length of $D_3$ and F. The projections of several lines between 520 $\mu\mu$ and 525 $\mu\mu$ were shorter than E and *b*. The same was observed of several lines between *b* and F, some of which showed no projections.

"Next after the observation just described came a vibration of shadows. The impression made was similar to that experienced by a traveller in a fast train, who watches from a window of his carriage the sudden passing of a length of trellis-work.

"While this was going on, I could still see the bright lines but not so distinctly as before. I kept my eye fixed on a small part of the spectrum, a group of lines between 500$\mu\mu$ and 505$\mu\mu$. Just at the disappearance of the continuous spectrum, the dark lines appeared luminous throughout; but I could not see more than about three-fourths of the lines of the group bright upon which I had fixed my eye. When this was over, the bright arcs of $D_3$ and F alone remained visible, and in the middle of the field of vision appeared the broad arc of 1474 K.

"The arcs of $D_3$ and F showed four prominences nearly equidistant from one another: two of them above and the two others beneath the moon's line of motion. The prominences had the same form in $D_3$ and F. One of them, that which appeared nearest the line of the motion of the moon towards the north, showed a weak continuous spectrum for the first 5 or 10 seconds. It was difficult to distinguish the colours and I could not see any dark lines in it. This continuous spectrum had the same breadth as the base of the prominence (see Plate XVII, fig. 1, in which

the arrow shows the direction of the motion of the moon's centre). The colours of this spectrum were not very bright, especially the green and the blue were weak while the orange and yellow were most prominent.

"The arc of 1474 K was since the beginning of totality steadily growing in breadth and brightness, till at 90 seconds before the end of totality it filled the whole field of vision. The arcs of $D_3$ and F now disappeared, leaving only the four bright spots of the prominences. Other arcs were not visible. I could not distinguish the form of the prominences in the corona-light.

"The light of the corona showed two dark rifts, parallel to the line of motion of the moon. They extended to the disk of the dark moon and nearly coincided with the two prominences that were nearest to the line of motion of the moon's centre. They were about four times as broad as the base of the prominences.

"To see how far the light of the corona extended I moved the telescope, but I could not find the end without turning the image of the dark moon in the 1474 K radiation entirely out of the field of the telescope. While keeping this image within sight, the extension of the corona, so far as it was visible to me, was equal to three solar diameters; and the light at the most distant part from the sun was still so bright, that it must have extended to double this distance (see Plate XVII, fig. 2). I detected no movement in the corona and the light seemed to be steady.

"By the movement of the instrument, the F line was turned out of the field and the C line appeared, the four prominences showed here the same form as in $D_3$.

"Forty seconds before the end, a continuous spectrum became visible between the two rifts, in the red part of the spectrum. The red and yellow were bright the green less so and only partly visible, the blue was entirely quenched by the light of the corona. Dark lines were not visible in it, and the colours did not coincide with those of the prominences and the corona, as the yellow began near the C line. It showed no distinct figure.

"The four prominences were still visible 25 seconds before the end; the two in the middle disappeared soon after; but the other two were still visible at the end of totality.

"Whilst still engaged upon the observation of the corona, suddenly a very bright continuous spectrum about one-tenth of the moon's disk appeared. I had to remove my eye from the instrument. Totality was over. It seemed I had turned one-half of the moon's image out of the field of the prisms, and thus the western side of the sun and the second flash entirely escaped my observation."

The three-inch equatorial in charge of Mr. Rishi was placed between the instruments of Dr. Mackichan and Father Haan and it was arranged that Mr. Rishi should give the position of any "white" prominence that he might observe to Father Haan. No such appearance was, however, noted. (See Plate XVI, fig. 1.)

## *XXIII.—The Coronographs; Photographs of the Corona.*

To take photographs of the corona the original intention was to mount a series of lenses of varying aperture and foci on the equatorial stand accompanying the six-inch Cooke Prismatic Camera, reserving the cœlostat for the latter instrument. The very late arrival of the instruments, however, compelled an alteration in the plan, and it was resolved only to utilise an ordinary six-inch lens of an astronomical telescope by Grubb and a four-inch portrait lens by Darlot for the direct photography of the corona.

The cœlostat had a twelve-inch mirror adapted for use at the fixed latitude of 18° N. The levelling screws, however, allowed of sufficient adjustment in altitude. The clock driving the mirror was independent of the rest of the instrument and was connected to the driving-worm of the cœlostat by a hook-joint. Both cœlostat and clock were fixed on independent concrete pillars about three feet high.

When first received the clock was absolutely out of order; very likely it was not tried before despatch and extensive alterations were required before it was set properly going. Unfortunately it was not provided with maintaining power; the little extra cost of the addition more than repays the outlay and it should not be left out particularly for eclipse purposes. The driving-weight consisting of a large stone block resting on an iron sheet platform was hung from a wooden gallows, the necessary drop being obtained by digging a small well underneath the gallows.

The adjustment of the cœlostat in meridian and altitude was effected by mounting a transit-theodolite on the upper end of the polar axis of the instrument. The method adopted was nearly the same as that described by Professor H. H. Turner on page 102 of Vol. LVII of the Monthly Notices of the Royal Astronomical Society. He says:—

"The adjustment of the axes of the cœlostat was effected very quickly by means of the attached declination theodolite. The level attached to the telescope makes it possible to adjust in altitude without any astronomical observation, for the latitude of the place can be taken from the chart with sufficient accuracy, and setting the telescope to the south declination equal to the co-latitude and in the meridian, the level should indicate horizontality. Index errors of the circle and level are estimated by reversal of the instrument. There is a slight uncertainty attending the placing of the telescope in the meridian, but this does not seriously affect the adjustment in altitude. If a cross level were made for the pivots of the telescope this uncertainty could be removed.

"To adjust in azimuth we must have an observation of the sun (or a star) at a distance from the meridian. Observing his declination (in reversed positions of the instrument and taking the mean) the instrument must be moved in azimuth until this observed declination agrees with that given in the Nautical Almanac. A very few trials, if the sun can be seen for half an hour, will soon indicate the true azimuth without any calculations within a minute or two of arc, though if the instrument is moved much the altitude observation should be repeated."

Regarding the position of the camera lens, after some consideration it was decided to place it horizontally in order to get a firm support. The azimuth angle was calculated by the formulæ given by Professor Turner in Vol. LVI, 8, of the M. N. R. A. S. This was found to be 20° 42′ 50″ north by west with an elliptical reflection from the cœlostat of 12 inches × 8·2 inches.

The camera lens, as previously stated, was an ordinary telescopic one by Grubb of 6″ aperture and 84″ focus, giving an image of the moon equal to 0·8 inch nearly. In order to obtain a more achromatic image the aperture was reduced to four inches by a diaphragm in front, and the lens was mounted in its usual tube on a wooden frame-work, strengthened with large cobble stones as previously described in the case

of the slit-spectroscope and siderostat. The instrument ready for work is shown in Plate XVIII.

The best photographic focus was obtained by trails of stars. The plates employed were of cabinet size, being Edward's backed isochromatic snapshot. The slides employed were the ordinary double ones of book pattern. They were considerably warped owing to the extreme dryness of the atmosphere, and after some trials I found a mixture composed of *ungentum simplex* (simple ointment) of the British Pharmacopœia, and some solid paraffin and lamp-black melted together the most efficient composition to make them light-tight. After filling in the plates the hot semi-fluid mixture was poured on the edges of the slides, the flaps rapidly brought together and clamped, and any excess of the composition on the outside was removed by vigorous rubbing with a rag. The joints were thus made perfectly light-tight and no trouble was subsequently found with the slides.

The exposures given were—

(1) One second.
(2) Two seconds.
(3) Five seconds.
(4) Twenty seconds.
(5) Two seconds.
(6) One second.

The coronograph was in charge of Mr. A. G. Hudson, Superintendent of the Bombay Revenue Survey. He was assisted by Mr. P. DeSouza (student) who let in and cut off the light from the lens by means of a cardboard screen at the call from Mr. Hudson.

The plates were developed tentatively with pyro-soda. As recommended by Barnard (Lick Observatory Report, Total Solar Eclipse, January 1, 1889) the developer was highly diluted and had a very small proportion of pyro, and the development was continued till further details ceased to appear.

The four-inch Darlot portrait lens of 24 inches focus was mounted in a fixed position and the exposures attempted were five, viz., instantaneous, one second, two seconds, one second, and instantaneous, on Edward's Isochromatic Snapshot plates backed. The exposures were carried out successfully by Mr. D. D. Kapadia, M.A., B.Sc. With a focus of 24 inches such short exposures cannot to any appreciable extent cause blurring of the image, and this was found to be the case as all the plates on development came out very successful.

### *XXIV.—General description of the Corona.*

Three plates taken with the larger coronograph, viz. Nos. 3, 5 and 6, and Plate No. 1 taken with the portrait lens are reproduced untouched at the end of the Report (see Plate XIX). They very well convey an idea of the inner and outer corona. The drawing of the corona given as frontispiece to the Report was made from

these plates by Mr. Henry Cousens, Superintendent, Archæological Survey, Bombay Presidency, the greater extensions being taken from his own photographs of the eclipse.

The features which immediately arrest attention are the "plumes" near the southern solar pole, and the great extension of the S. W. streamer which on some of the smaller plates can be traced to 2½ diameters. The polar rays on the north though quite distinct still merge into shapes more or less like the streamers. The polar rays in both regions are nearly straight in the centre near the poles, but further away they curve outwards. The principal streamers are in the north-east, north-west and south-west quadrants and they as well as all other streamers show distinctly Raynard's synclinical structure. The great south-west streamer is more radial than the other two. The fourth smaller streamer in the north-west is composed of three separate rod-like forms, the upper two of which are almost parallel and of very definite outline.

No definite general connection can be traced from the photographs between the prominences and the principal streamers. The large prominence in the S. E. quadrant is indeed situated in the centre of the base of the S. E. streamer, but no such correspondence exists between the other prominences and streamers. The prominence in the N. E. quadrant is in a much higher latitude than the centre of the streamer, and the set of three remarkable prominences in the N. W. quadrant cannot in any way be said to be connected with the three streamers in that quadrant. The largest south-west streamer is moreover unaccompanied by any decided solar eruption.*

## *XXV.—Type of the Corona.*

Coronæ have been divided into two main types, viz., the *Sun-spot maximum* and *Sun-spot minimum.* "When sun-spots are numerous the corona appears to be most fully developed above the spot zones, thus offering to our eyes a rudely quadrilateral contour," but when the spots are few the whole aspect changes, "north and south a series of short vivid electrical-looking flame brushes diverge with conspicuous regularity from each of the solar poles" and the synclinical streamers instead of being radial are more or less parallel to the equator. The question was first investigated in some detail by Mr. Raynard in his monumental work, Memoirs of the Royal Astronomical Society, Vol. XLI, and he has there reviewed the forms of the coronæ from 1715 to 1878. Hansky in his Report on the Russian Expedition to Novaya Zemlya in 1896 has brought together in a very interesting memoir accompanied by an instructive plate the varying forms of the corona. A careful examina-

* I am aware that this is opposed to the views of other observers, but the evidence of any such invariable connection at *this* eclipse is, I think, very slender. The photograph reproduced in the Report of the Survey of India shows an intimate relation between the three prominences and streamers in the N. W. quadrant. An examination of the original negative has, however, revealed the fact that no such correspondence is recorded there.

tion of the most reliable drawings and photographs since 1860, however, indicates that there are sub-types of coronæ and that the corona of 1898 belongs to one of these. Evidently the form does not change only with the general maximum or minimum period, but with what Newcomb (Astr. Phy. J., Vol. XIII) has called the "mid-phase rising" and "mid-phase falling" epochs, and any abnormal activity of solar spots has also a decided effect on the form.

In Plate XX, I have collected together representations of the corona since 1860 from the most reliable drawings and photographs available and in Plates XXI and XXII are shown how the time occurrence of each eclipse was related to Wolf's "Sun-spot frequency" numbers for every month of the year and also for each year.

*Sources from which the drawings have been made.*

1860, July 18. Weedon's drawing, Raynard's Report, page 543.

1867, Aug. 29. Grosch's drawing, Raynard's Report, page 581.

1868, Aug. 18. Bullock's drawing, Raynard's Report, page 590.

1869, Aug. 7. Meek, Schott and Macleod's drawings, U. S. Coast Survey Report.

1870, Dec. 22. Brother's photograph and Corallo's drawing, Raynard's Report, page 642 and Plate 6.

1871, Dec. 12. Lindsay-Davis's photograph, Raynard's Report, Plate 7.

1874, April 16. Stone's drawing, Raynard's Report, page 715.

1875, April 6. Lockyer and Schuster's photograph, Philosophical Transactions, Vol. 169, Plate 12.

1878, July 29. Peer's photograph, U. S. Naval Observatory Report, Plate 10.

1880, Jan. 11. Davidson's drawing, Hansky's Novaya Zemlya Report.

1882, May 17. Schuster and Wesley's composite drawing, P. T., Vol. 175, Plate 13.

1883, May 6. Abney's photographs, P. T., Vol. 180 A., Plates 1 and 2.

1885, Sep. 8. Graydon's drawings, Todd's Eclipses, page 149, and "Nature," Vol. 32, page 632.

1886, Aug. 29. Pickering's photograph, Harvard Annals, Vol. 18, and Schuster's photograph, P. T., Vol. 180 A., Plate 10.

1887, Aug. 19. Niesten's photograph. in his Report.

1889, Jan. 1. Barnard's photograph Lick Observatory Report, Plates 1 and 2.

1889, Dec. 22. Perry's photograph, "Observatory" XIII, and Burnham's photograph, Lick Observatory Report, Plate I.

1893, April 16. Schaeberle's photograph, Lick Observatory Report and Hansky's Novaya Zemlya Report. Deslandre's photograph in his Report, Plate iii.

1896, Aug. 9. Baden Powell's photograph, P. T., Vol. 190, Plate ii; and Kostinsky's Photograph, Hansky's Report.

1898, Jan. 22. Jeur photographs.

1900, May 28. Gautier-Riggenbach's drawing, Archives des Sciences Physiques et Naturelles for 1900, Plate I, and Wesley's composite drawing, B. A. A. Report.

In the following table I have given the dates of sun-spot epochs as determined by Newcomb (Astrophysical Journal, XIII) together with the dates of eclipses since 1860. In the third column of the table are given the mean sun-spot frequencies for the month and also for the year in which each eclipse happened :—

| | Date. | Mean Sun-spot frequency at Eclipse. |
|---|---|---|
| Maximum ... | 1860·2 | |
| *Eclipse* ... ... | 1860·54 | Monthly = 116·7<br>Annual = 95·7 |
| Mid-phase falling . | 1862·9 | |
| Minimum ... | 1867·2 | |
| *Eclipse* ... ... | 1867·66 | Monthly = 4·9<br>Annual = 7·3 |
| *Eclipse* ... ... | 1868·63 | Monthly = 34·4<br>Annual = 37·3 |
| Mid-phase rising . | 1869·3 | |
| *Eclipse* ... ... | 1869·60 | Monthly = 79·6<br>Annual = 73·9 |
| Maximum ... | 1870·9 | |
| *Eclipse* ... ... | 1870·97 | Monthly = 130 0<br>Annual = 139·1 |
| *Eclipse* ... ... | 1871·94 | Monthly = 90·3<br>Annual = 111·2 |
| Mid-phase falling. | 1873·2 | |
| *Eclipse* ... ... | 1874·29 | Monthly = 32·0<br>Annual = 44·6 |
| *Eclipse* ... ... | 1875·26 | Monthly = 29·1<br>Annual = 17·1 |
| *Eclipse* ... ... | 1878·57 | Monthly = 0·1<br>Annual = 3·4 |
| Minimum ... | 1878·8 | |
| *Eclipse* ... ... | 1880·03 | Monthly = 24·0<br>Annual = 32 3 |
| Mid-phase rising . | 1880·7 | |
| *Eclipse* ... ... | 1882·37 | Monthly = 64·1<br>Annual = 59 6 |
| *Eclipse* ... ... | 1883·34 | Monthly = 32·1<br>Annual = 63·7 |
| Maximum ... | 1883·7 | |
| *Eclipse* ... ... | 1885·68 | Monthly = 39·6<br>Annual = 52·1 |
| Mid-phase falling . | 1886·1 | |
| *Eclipse* ... ... | 1886·65 | Monthly = 16·9<br>Annual = 25·4 |
| *Eclipse* ... ... | 1887·63 | Monthly = 21;4<br>Annual = 13·1 |
| *Eclipse* ... ... | 1889·00 | Monthly = 0·8<br>Annual = 6·3 |
| Minimum ... | 1889·4 | |
| *Eclipse* ... ... | 1889·97 | Monthly = 6·7<br>Annual = 6 3 |
| Mid-phase rising . | 1891·8 | |
| *Eclipse* ... ... | 1893·29 | Monthly = 88·1<br>Annual = 84·9 |
| Maximum ... | 1893·6 | |
| Mid-phase falling | 1896·0 | |
| *Eclipse* ... .. | 1896·6 | Monthly = 27·2<br>Annual = 41·8 |
| *Eclipse* ... ... | 1898·06 | Monthly = 30·2<br>Annual = 26·7 |
| *Eclipse* ... .. | 1900·4 | Monthly = 15·2<br>Annual = 9·5 |
| Minimum .. | About 1901·7 | |

An inspection of Plate XX will show that though on the whole there is a great family resemblance between the forms of coronæ at similar phases of solar activity from cycle to cycle, there are many instances of marked variation from a given type.

In Plate XXIII the coronæ are arranged in descending order of mean annual sun-spot frequencies at the epochs of the eclipses. Here the devlopement of the

corona from the maximum to the minimum form is more gradual and regular and in Plate XXIV where they are arranged in the descending order of absolute monthly sun-spot frequencies the development of the coronal form is still more marked.

In a complete investigation of the subject not only the sun-spot frequencies preceding each eclipse by a definite period should be considered, but other indications of solar activity such as faculæ and prominences ought to be also taken into account. Moreover, the forms of coronæ as depicted are not all reliable and the same weight cannot be assigned to them all. It is only of late that both the inner corona and its outer extensions at an eclipse have been successfully and adequately photographed. A long series of such photographs taken with identical instruments from eclipse to eclipse alone can contribute to a satisfactory discussion of the problem. However, there seems to be very little room for doubting that the coronal features change in sympathy with the state of absolute solar activity. In a separate memoir I propose to undertake a further detailed investigation of this most interesting question in solar physics.

## *XXVI.—Drawings of the Corona.*

To sketch the outline of the corona occulting discs were employed on the principle explained in my " Instructions " (see Appendix). Two of these discs supported on poles about fifteen feet high are seen sticking out above the screen in the photograph of the Observing Party (Plate VI). Mr. H. F. Beale, Principal of the College of Science, and Messrs. H. G. Kadne and J. R. Yadav, Draftsmen of the Archæological Department, shared the work between themselves. Mr. Beale sketched the N. W. quadrant, Mr. Yadav from N. W. to S. E., and Mr. Kadne from S. E. to N. The combined drawing is given in Plate XXV and its general resemblance to the true aspect of the corona as given in Mr. Cousens' drawing from photographs is on the whole very satisfactory.

A sketch of the corona made by the Reverend Mr. A. Abbott of the American Maráthi Mission, Bombay, with the help of an opera glass is also given in Plate XXVI.

## *XXVII.—Visibility of the Corona out of totality.*

The longest recorded duration of the visibility of the corona before or after the eclipse is 12 minutes. This was observed by M. F. Petit at the eclipse of 1860. He says " J'ai commencé á apercevoir l'auréole autour de soleil 12 minutes avant de premier moment de l'obscurité" (Raynard, Eclipse Report, page 83). During the American eclipse of 1878 Professor Upton saw it for 7 minutes 15 seconds after totality and Professor Langley " without any other precaution than masking the eye from direct sunlight " saw it for over 4 minutes after totality. Recognising the importance of an accurate determination of the duration of the phenomenon, I had told off two independent observers for the purpose. The task was entrusted to Mr. M. S. Murzban and Master P. K. Naegamvala. They were each provided with

a stop-watch and were instructed to shield their eyes with card-board screens so as to prevent any light reaching them from the south-west quadrant of the eclipsed sun at least a minute before the third contact and to carefully direct their attention to the opposite quadrant. They were to start their watches at the call for third contact and to stop them when the last trace of the corona had disappeared. At the end of their observations the stop-watches were brought to me and I found the duration recorded by Mr. Murzban to be 17 minutes 44 seconds and by Master Naegamvala 17 minutes 48 seconds.

It is difficult to realise that the corona could have been in evidence so long, but looking at the independent nature of the two observations and the precautions observed, I see no grounds to question their accuracy.*

### *XXVIII.—Shadow bands.*

The observations of shadow bands were entrusted to Messrs. Joshi, Sataravala and Godbole, students of the College of Science. White sheets were spread on the ground and the observers were provided with compass, stop-watch and measuring rods. The first observer counted the breadth of the bands, the second their number and the third their direction.

Both before and after totality the breadth of the bands was estimated to be two inches with an interval of eighteen inches between them. They were reported as "very very slightly curved."

The number of bands before totality was counted at twenty-five in seven seconds and a half and after totality at eighteen in four seconds and a quarter. "They were darker and came faster before totality, but they came on slowly and were more faint at the end of totality."

"The bearing of the bands," Mr. Godbole reported, "was $115\frac{1}{4}°$. They went from N. E. to W. Their bearing after totality was $147\frac{1}{2}°$ and they went from E. to W. The bands appeared *like waves* nearly an inch or two in breadth; they went very fast and gave the idea at first sight as if the cloth was shaken by wind." Mr. H. G. Tomkins, who was just behind the observer, tells me that Mr. Godbole actually rushed to the cloth to prevent it from apparently moving away, so strong was the illusion!

The Reverend Dr. G. P. Taylor also observed the shadow bands in the neighbourhood of the eclipse camp and his notes of observations are given below :—

*Station of observation.*—The highest point of slightly rising ground about a mile or a mile and a half east of the Railway station at Jeur.

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* A remarkable observation in support of the possibility of seeing the corona for a considerable time out of totality is given on page 92 of the Report of the British Astronomical Association of the Eclipse of May 1900, where Mr Weir is reported to have seen the corona, without specially looking for it, "quite ten minutes before totality."

*Time of observation.*—Before and after totality; in each case during about 3 minutes.

*Breadth of shadow bands.*—The first few to be seen appeared as though each was some five or six inches broad; but these were soon succeeded by bands each apparently not more than about two inches broad.

*Interval between shadow bands.*—The interval between the first few (broad) bands seemed to be about two feet, but the interval between all the succeeding (narrower) bands was apparently some *four* inches.

*Speed of passage of shadow bands.*—After the first four or five the speed became much accelerated, and the shadow bands succeeded each other quicker than could be counted. I should think six or eight passed over the same spot in a second, and this rate was maintained till totality.

*Direction of motion of shadow bands.*—The bands flitted across the sheet almost precisely from N. E. to S. W.

## XXIX.—*Visibility of Stars and Planets.*

Professor R. N. Apte, M.A., LL.B., undertook to observe the visibility of planets and stars. He was provided with a copy of the chart specially prepared for the purpose by the Survey of India. He observed Venus 4½ minutes and Mars half minute before totality and he could see Mercury for half a minute after the end of totality. Mr. V. K. Kanitkar, L.C.E., discerned Venus eight minutes before totality and kept it in view with the naked eye from that moment until 19 minutes 47 seconds after totality. Venus and Mars were observed by several other persons both before and after totality. No stars, however, were observed.

## XXX.—*Meteorological Observations.*

A thatched hut of a pattern similar to that adopted by the Indian Meteorological Department was erected (see Plate XVI, fig. 1) and observations were commenced from January 14th, a week before the eclipse, and were continued till January 30th, a week after the event.

The following instruments were installed for various observations:—

- A Richard eight-day thermograph.
- A Richard eight-day barograph.
- A Watkin's aneroid barometer.
- A self-registering maximum thermometer.
- A self-registering minimum thermometer.
- A wet-bulb hygrometer.
- A black bulb radiation maximum thermometer.
- A radiation minimum thermometer.
- A very delicate standard thermometer.

During the fortnight readings were taken every day at 10-20 A.M. and 4-20 P.M. Madras Mean Time, and also at 1-20 P.M., near the time when totality was to take place. Wind observations were also made regularly during the week preceding the

eclipse. Unfortunately the records were lost at the end of the fortnight by the custodian; some of the rough notes of observations were, however, preserved and the following results are gleaned from them.

*Temperature.*—The most marked feature was the large daily range averaging 35° to 40° F., the greatest change taking place between 8 A.M. (7-30 A.M. local time) and noon. This is well shown on the thermograph for January 14—17 reproduced on Plate XXVII.

*Table of Temperature Readings.*

| Date. | Time M. M. T. | Reading. | Remarks. |
|---|---|---|---|
| January 14 ... | 8-0 A.M. | 11·7° C. | Minimum. |
| | 1-20 P.M. | 29·4° C. | |
| | 4-0 P.M. | 30·3° C. | Maximum. |
| January 15 ... | 7-40 A.M. | 10·3° C. | Minimum. |
| | 1-20 P.M. | 28 3° C. | |
| | 4-0 P.M. | 30·0° C. | Maximum. |
| January 16 ... | 10-20 A.M. | 14·4° C. | Minimum. |
| | 1-20 P.M. | 30·0° C. | |
| | 4-20 P.M. | 31·9° C. | Maximum. |
| January 17 ... | 10-20 A.M. | 11·7° C. | Minimum. |
| | 1-20 P.M. | 30·0° C. | |
| | 4-20 P.M. | 31·7° C. | Maximum. |
| January 18 ... | 10-20 A.M. | 11·1° C. | Minimum. |
| | 1-20 P.M. | 30·0° C. | |
| | 4-20 P.M. | 32·2° C. | Maximum. |
| January 19 ... | 10-20 A.M. | 10·6° C. | Minimum. |
| | 1-20 P.M. | 29·5° C. | |
| | 4-20 P.M. | 31·1° C. | Maximum. |
| January 20 ... | 10-20 A.M. | 8·1° C. | Minimum. |
| | 1-20 P.M. | 28·7° C. | |
| | 4-20 P.M. | 31·5° C. | Maximum. |

The *day* variations of temperature are graphically shown in Plate XXVIII.

*Variation of Temperature during the progress of the Eclipse.*

| Date. | Time. | Reading. | Date. | Time. | Reading. |
|---|---|---|---|---|---|
| January 22 ... | 12-0 noon | 26·5° C. | January 22 ... | 1-10 P.M. | 25·0° C. |
| | 12-10 P.M. | 26·5° C. | | 1-20 P.M. | See next table. |
| | 12-20 P.M. | 26·8° C. | | 1-30 P.M. | 24·5° C. |
| | 12-30 P.M. | 26·5° C. | | 1-40 P.M. | 24·8° C. |
| | 12-40 P.M. | 26·0° C. | | 1-50 P.M. | 25·3° C. |
| | 12-50 P.M. | 25·8° C. | | 2-0 P.M. | 25·5° C. |
| | 1-0 P.M. | 25·8° C. | | 2-10 P.M. | 26·0° C. |

These are shown graphically in Plate XXIX, fig. 1.

*Variations of Temperature during Totality.*

| Time. | Reading. | Time. | Reading. |
|---|---|---|---|
| At second contact ... | 25·0° C. | 70 seconds after ... | 24·7° C. |
| 10 seconds after ... | 24·8° C. | 80 „ „ ... | 24·7° C. |
| 20 „ „ ... | 24·8° C. | 90 „ „ ... | 24·5° C. |
| 30 „ „ ... | 24·8° C. | 100 „ „ ... | 24·5° C. |
| 40 „ „ ... | 24·8° C. | 110 „ „ ... | 24·5° C. |
| 50 „ „ ... | 24·8° C. | 120 (third contact) ... | 24·5° C. |
| 60 „ „ ... | 24·8° C. | | |

On Plate XXIX, fig. 2, these temperature changes are graphically shown. It will be noticed that the total fall during the progress of the eclipse was only 2·0° C. and the minimum temperature was reached 90 seconds after the commencement of totality.

The variation of temperature was also noted by Mr. R. B. Joyner, C.I.E., Superintending Engineer, Central Division, at Bársi, a station further south on the line of totality, and he found that the temperature fell from 80·5° to 77° F., *i.e.* 3·5° F., which is very nearly equal to 2° C.

The maximum radiation thermometer readings were from day to day as follows :—

| Date. | Time. | Reading. | Date. | Time. | Reading. |
|---|---|---|---|---|---|
| January 17 ... | 1-20 P.M. | 60·1° C. | January 20 ... | 10-20 A.M. | 52·9° C. |
| | 4-20 P.M. | 60·6° C. | | 1-20 P.M. | 61·2° C. |
| January 18 ... | 10-20 A.M. | 60·6° C. | | 4-20 P.M. | 61·1° C. |
| | 1-20 P.M. | 60·7° C. | January 21 ... | | |
| | 4-20 P.M. | 61·4° C. | January 22 ... | 1-20 P.M. | 58·0° C. |
| January 19 ... | 10-20 A.M. | 54·2° C. | | | |
| | 1-20 P.M. | 59·8° C. | | | |
| | 4-20 P.M. | 60·4° C. | | | |

*Wet-bulb Thermometer.*

During the progress of the eclipse, the wet-bulb thermometer varied as follows :—

| Time. | Reading. | Time. | Reading. |
|---|---|---|---|
| 12-20 P.M. .. | 15·8° C. | 1-20 P.M. ... | 14·2° C. |
| 12-30 P.M. ... | 15·2° C. | 1-30 P.M. ... | 14·2° C. |
| 12-40 P.M. ... | 15·0° C. | 1-40 P.M. ... | 14·4° C. |
| 12-50 P.M. ... | 14·9° C. | 1-50 P.M. ... | 14·7° C. |
| 1-0 P.M. ... | 14·5° C. | 2-0 P.M. ... | 14·8° C. |
| 1-10 P.M. ... | 14·3° C. | 2-10 P.M. ... | 15·2° C. |

This is shown graphically in Plate XXX.

The *barometer* did not show any appreciable fluctuation during the eclipse.

*Wind.*

The following record speaks for itself :—

| Date. | Time. | Direction. | Remarks. |
|---|---|---|---|
| January 16 ... ... | 4-20 P.M. | W. | Gentle. |
| January 17 ... ... | 10-20 A.M. | W. | Moderate. |
| | 1-20 P.M. | S.W. | Moderate. |
| | 4-20 P.M. | W. | Moderate. |
| January 18 ... ... | 10-20 A.M. | N.W. | High. |
| | 1-20 P.M. | W. | High. |
| | 4-20 P.M. | S.W. | Very gentle |
| January 19 ... ... | 10-20 A.M. | ...... | Calm. |
| | 1-20 P.M. | W. | High. |
| | 4-20 P.M. | W. | Moderate. |
| January 20 ... ... | 10-20 A.M. | W. | Moderate. |
| | 1-20 P.M. | S.W. | High. |
| | 4-20 P.M. | S.W. | High. |

During the progress of the eclipse the wind was :—

| Time. | Direction. | Remarks. |
|---|---|---|
| At 12-55 P.M. ... | W. | Very gentle. |
| 1-0 P.M. ... | N. W.W. | Very moderate. |
| 1-10 P.M. ... | W. | Very gentle. |
| 1-17 P.M. ... | W. | Moderate. |

but during totality there was a rapid change; the breeze fell to a very gentle zephyr, the direction varying between W.N.W. and W.S.W.

### *XXXI.—Colour of the Landscape and General Illumination.*

During totality the light was particularly bright, very much more so than that of the full moon in the most favourable weather. No lights were necessary for help in any operations, the seconds-hand on an ordinary watch being easily read. The colour of the landscape was of a pronounced neutral tint, very much similar to that seen through ordinary smoke coloured glare-glasses.

### *XXXII.—Effects on Plants and Animals.*

Messrs. P. T. Pavri and R. D. Naegamvala were specially told off to make observations on animals. Several hundred yards north of the camp, the cattle in camp were driven over the fields and left there grazing hours before totality.

Mr. Pavri's report is given below *in extenso* :—

" For about an hour after first contact there was no visible effect upon the animals grazing quietly among the fields.

" Birds were heard singing merrily among the confused cawing of many crows ready for an attack upon the meat by the side of the butcher located in the vicinity. The deer was all life and activity, and disliking all checks but those of nature, broke the tether, and fled past the keepers nimbly along the woods. But a piece of the tether left along its neck getting entangled within some bushes and trees it was recaught, and led again into the service of man.

" But now follows some change. Some goats and lambs feel a sense of uneasiness stealing over them. The deer looks with wondering eyes, and the donkeys appear a little depressed. Here a few of the hens, searching for grain vigorously among the fields, begin to cry aloud as at evening time preparing for their night's rest. The ponies and a few of the cows feed intermittently, but the rest with the buffaloes and the oxen go on grazing, looking totally unconcerned. The song of birds falls off gradually, and the kites and such other birds soaring high up during day time begin to descend slowly. The dogs are moaning piteously ; the crows go to roost amongst a confusion of caw caws. The blue bright sky changes gradually to dull purple, and the planets Venus and Mars appear in all their splendour, followed later on by Mercury, so rarely seen at other times. As the landscape grows darker and darker and the sky more and more dusky, some of the goats sit down among grass, and the donkeys begin to march quick, rank and file, towards the camp of the observers ; but they are given the order for halt, followed simultaneously by a charge of the wooden bayonets by the keepers.

" Now out upon the darkness flashes 'the glory of the incomparable corona,' and during a sense of hushed expectancy, the earth seems to have rested for a while. Some crows look a little terrified, and the hens gather together over one another near a heap of stones below a tree. The deer looks with resigned eyes and everything is as quiet and still as the dead of night, except the sound made by the buffaloes and some of the cows which take no interest in the state of affairs going around them, but are deeply absorbed in the more important task of stuffing their bellies and of doing random havoc among the *jowári* cultivation where they are allowed to ramble at will.

" A few kites which could not get down before totality are seen descending slowly here and there. Preceding the emersion of the sun's body from the total eclipse, a sense of chillness crosses the air, but soon after the sun light strikes the landscape, the earth seems to come to life again, some birds, commonly known as 'Kolsa,' (King-crow) come singing and perch on the very tree before us.

Some of the kites, which had come only half-way down, knowing themselves mistaken, go again soaring upwards in the sky. The animals, shaking off their drowsiness, continue their daily routine of life, and nature seems to revive gradually."

Mr. R. Naegamvala reported that five or six minutes before totality he noticed crows cawing and dogs barking. During totality some kites were flying about. One hen began to cackle just before totality, but stopped at once during totality. Doves commenced to coo before totality and stopped during totality. There was no visible effect upon the cattle.

Mr. V. K. Kanitkar noticed crows cawing twenty minutes, dogs barking five minutes, and doves cooing three minutes before totality.

Principal Beale reported crows cawing eight minutes before totality ; no birds were visible after this till the kites came out again after totality. Five minutes before totality dogs were barking as is their wont in villages in the evening. There was no barking before this or after the eclipse.

Master P. Naegamvala states that he noticed after totality the birds chirping as they do in the morning. There were no small birds to be seen before totality, but after totality they were seen flying about as usual.

*Effect on Plants.*

Professor Woodrow noticed the *Leguminosæ* plants closing their leaves before totality. Mr. Kanitkar observed the leaves of the Tarvad (*Cassia auriculata*) closing forty minutes before totality, and Master P. Naegamvala of *Crotolaria* plants behaving in the same manner before totality.

# APPENDIX.

## INSTRUCTIONS FOR OBSERVING THE TOTAL ECLIPSE OF THE SUN, JANUARY 22, 1898.

1. In the Bombay Presidency the Eclipse will be total within the tract marked in the accompanying map by the dark shaded band.

Along the central line of the tract the duration of totality will be longest, and it is recommended that observers should locate themselves as near the central line as possible.

The following table gives the time and duration of totality at the stations mentioned :—

| Stations. | Beginning of Totality Mad. M. T. | Duration of Totality. |
|---|---|---|
| | H. m. s. | H. m. s. |
| Rájápur ... ... ... ... | 1 13 0 | 0 2 2 |
| Masur, Southern Mahratta Railway ... ... | 1 17 0 | 0 2 8 |
| Between Jeur and Kem, Great Indian Peninsula Railway . | 1 21 0 | 0 2 4 |
| Valur (Nizam's Territory) ... ... ... | 1 25 0 | 0 2 1 |
| Dhámangaon, Great Indian Peninsula Railway ... | 1 29 0 | 0 1 57 |

2. *Description of a Total Eclipse* :—" As the entire duration of an eclipse, partial phases and all, embraces two or three hours, often for an hour after 'first contact' insects still chirp in the grass, birds sing, and animals quietly continue their grazing. But a sense of uneasiness seems gradually to steal over all life. Cows and horses feed intermittently, bird-songs diminish, grasshoppers fall quiet, and a suggestion of chill crosses the air. Darker and darker grows the landscape. So much as five minutes before the total obscurity it may be possible to detect strange wavering lines of light and shade dancing across the landscape—the 'shadow bands,' as they are called,—a curious and beautiful effect not yet fully understood.

" Then with frightful velocity the actual shadow of the moon is often seen approaching, a tangible darkness advancing almost like a wall, swift as imagination, silent as doom. The immensity of nature never comes quite so near as then, and strong must be the nerves not to quiver as this blue-black shadow rushes upon the spectator with incredible speed. A vast, palpable presence seems overwhelming the world. The blue sky changes to gray or dull purple, speedily becoming more dusky, and a death-like trance seizes upon everything earthly. Birds, with terrified cries, fly bewildered for a moment and then silently seek their night quarters. Bats emerge stealthily. Sensitive flowers, the scarlet pimpernel, the African mimosa, close their delicate petals, and a sense of hushed expectancy deepens with the darkness. Sometimes the shadow engulfs the observer smoothly, sometimes apparently with jerks; but all the world might well be dead and cold and turned to ashes. Often the very air seems to hold its breath for sympathy, at other times a lull suddenly awakens into a strange wind, blowing with unnatural effect.

" Then out upon the darkness, gruesome but sublime, flashes the glory of the incomparable corona, a silvery, soft, unearthly light, with radiant streamers, stretching at times millions of

uncomprehended miles into space, while the rosy, flaming protuberances skirt the black rim of the moon in ethereal splendour. It becomes curiously cold, dew frequently forms, and the chill is perhaps mental as well as physical.

"Suddenly, instantaneous as a lightning flash, an arrow of actual sunlight strikes the landscape, and the earth comes to life again, while corona and protuberances melt into the returning brilliance, and occasionally the receding lunar shadow is glimpsed as it dies away with the tremendous speed of its approach."*

3. Amateur observers can render valuable help by making observations which may fall under one or more of the following heads :—

(a) Sketches of the *outline* of the corona.
(b) " " *details* of the outer corona or a part of it.
(c) Sketches of the inner corona.
(d) Photographs of the corona.
(e) Duration of totality.
(f) Duration of the visibility of the corona.
(g) Variation of temperature, humidity, barometric pressure, direction of the wind, &c., during the eclipse.
(h) Shadow-bands.
(i) Effect on plants, animals, &c.

(a) *Sketches of the outline of the Corona.*—The corona may be divided roughly into two parts, viz., the brighter or "inner" corona and the fainter or "outer" corona. To sketch the latter the observer must be provided with a disc having a diameter about 1/60th of that of the distance of the observer from the disc. It is desirable to attach to the disc two hoops of bamboo concentric with the disc of respectively two and three times the diameter of the disc; the hoops should be fixed to the disc by two cross pieces at right angles to one another. All the parts of the disc, hoops, &c., must be painted dead-black. As the average altitude of the sun will be 50°, it will be necessary to fix the disc at a height 1·2 times the distance of the observer from the disc, as measured along the ground, in order to hide the sun and the brighter parts of the corona. On the other hand, it is not desirable to be too near the disc—a distance of 30 to 50 feet is to be recommended; it will be, therefore, observed that the disc will have to be hoisted up to a height ranging from 36 feet to 60 feet. Perhaps the best arrangement will be to attach the disc to a sufficiently long pole, with one of the cross-bars vertical, and to fix the pole on the roof of a building. Wherever possible, two or three days before the day of the Eclipse, at the predicted time of totality the disc must be [illegible] in azimuth and the exact spot where the observer should place himself so as to hide the sun must be ascertained. On the following day it will be found necessary to shift the previous position slightly. A couple of such observations will indicate the average daily shift in position, and the exact position of the observer for the day of the Eclipse may thus be carefully fixed upon. The observer must also provide himself with a sheet of stiff drawing paper 12″ × 12″, with a diagram as shown in Plate I.§ The inner black disc intended to represent the eclipsed sun is 2 inches in diameter and the outer circles are 4 inches and 6 inches, respectively. Any other scale is admissible, but it is highly desirable to stick to one uniform size.

The observer must also provide himself with a bull's-eye or other lantern, arranged to throw the light on the drawing paper only, in case it is found necessary, and have it ready lighted. He must get his eyes bandaged ten or fifteen minutes before the predicted time of totality, and on totality

* Todd's "Total Eclipses of the Sun." (§ Not reproduced.)

being announced, and not before, the bandage must be removed. He must then draw the outer *extreme* limits of the corona with deliberation and care. Should time permit, he should go over the drawing again and correct it wherever necessary. In no case should any attempt be made to retouch or tamper with the drawing in any manner after the totality is over. Plate II shows one such sketch actually drawn. Wherever the corona fades away so gradually as to make it impossible to say where it actually terminates, the boundary must be indicated by a serrated outline as on the right hand side in Plate II. (Not reproduced.)

(*b*) *Sketches of the details of the Outer Corona.*—These should be made with the help of the disc and in the manner above mentioned; but it will be well to have a party of four observers, and for each observer to restrict himself to one quadrant only, trying faithfully to delineate the streamers and filaments. Plate III gives a fair idea of the nature of the drawings expected. It will prove of still greater value if an observer will restrict himself to *one single* streamer and delineate it with the utmost care. In this latter case an opera glass conveniently strapped to a stand or pole near at hand may prove useful in revealing faint and delicate details.

(*c*) *Sketches of the Inner Corona.*—The observer must not look at the sun till the eclipse is total; then without the intervention of the disc mentioned in paras. (*a*) and (*b*) he must rapidly sketch the rose-coloured prominences round the dark disc of the sun and also draw the forms and directions of the streamers and filaments roughly up to the first inner circle on the drawing-sheet, *i.e.*, extending every way to half the diameter of the dark moon. If the light be too dazzling to the eye, it will be well to interpose a piece of glass of neutral tint or one slightly smoked.

(*d*) *Photographs of the Corona.*—It is presumed that the cameras available will not be provided with any arrangement to follow the sun.

The best form of the camera is one made out of boards in the form of a box of the requisite length, the next is the old form of the rigid body camera, and the one the least to be recommended is the ordinary bellows-body camera.

The diameter of the lens should not be less than one inch, the diaphragm slit should be covered up and no diaphragm should be employed. It is desirable to use as long a focus as possible in order to obtain a large enough image. It is, therefore, advisable in every case (unless the lens is a single "view" lens or of the "tele-photo" type) to use only one component of the combination. In the case of "portrait" lenses better results will be produced by unscrewing the black lens and replacing it by the front lens; with the "rapid rectilinear" type, it will be best to remove the front lens, and if the combination be of the "wide-angle" pattern, then the back lens may be removed and the front lens left *in situ*, convex surface to the sun.

The camera must be previously very carefully focussed on the moon or stars. Failing this a very distant object, say one mile off, may be exactly focussed and the distance measured between the centre of the back of the lens and the inner side of the ground glass, and then the distance lessened by the amount determined by the formula:—

$$x = \frac{f^2}{d}.$$

Thus, for instance, if $d$ is 1 mile and $f$ is equal to 20 inches, the correction is 1/158th of an inch and the distance between the lens and the ground glass must be *shortened* by that amount. It will be, therefore, observed that with lenses of ordinary focal lengths, focussing on very distant objects three or four miles away, as for instance on distant clouds, will bring the lens practically in focus for the sun.

The camera must be elevated to the proper altitude, which is for Rájápur 51°, Masur 52°, Jeur 50°, and Nagpur 46°.

The camera must next be pointed to the sun at the calculated time of totality during the preceding two or three days and the daily shift of the image observed and allowed for as in (*a*). Do not attempt to change the elevation of the camera unless you can do it conveniently; a shifting in azimuth will be enough. If a small telescope is available, it may be strapped to the camera and used as a "view-finder" and the latter put into the right position almost within a minute or two of totality. Two riflesights even may be used advantageously for the purpose.

The fastest plates available should be used and the exposures should not exceed two seconds. If the observer is prepared to make six exposures, two of them must be instantaneous, two of half second each, and one each of one and two seconds' durations, respectively.

Before making each exposure, the greatest care must be taken to ensure absolute freedom from vibration or tremor in the camera; a single photograph well taken will be worth more than a dozen pictures carelessly secured.

In order to bring out the fainter details and extensions of the corona without obliterating the higher lights, the developer must be freely diluted with water and pyro employed in much smaller quantity than usual. Use the developer as cold as possible, and the development may be continued even for an hour, keeping the plate under cover and rocking it continuously. Cease developing when the rebates of the dark slide begin to appear on the plate. If the image be thin, a little pyro may then be added to the developer and density secured, but great care must be taken not to obliterate the fainter outer details by over-developing at this stage. The negative must not be varnished. A copy or print must be secured and the original negative sent carefully packed.

(*e*) *Duration of Totality.*—For this purpose it will be desirable to have two observers if [illegible]. An opera glass or small telescope about one inch aperture and strips of green glasses of varying depths will be required. The sun must be carefully scrutinised through the opera glass or telescope, as it grows to be a very narrow crescent, using the green glasses to reduce the glare; *at the moment* the last ray of the sun disappears (if possible before the rose-coloured prominences come to view), the observer must call out "*time*." This must be recorded by the other observer to the nearest second, who must be previously paying *undivided* attention to the face of the watch. The time observed should be immediately noted down and the first observer must be again ready to detect the first appearance of light on the opposite side of the sun. "*Time*" must be instantly called and recorded as before. A lighted lamp will be necessary in all probability to read the hands of the watch. With a [illegible], only one observer can perform both functions, noting down the duration of totality afterwards at leisure.

(*f*) *Visibility of the Corona.*—The time of beginning of totality must be noted as before, and shielding the eyes from the south-west corner of the sun where the light will re-appear, the observer must carefully direct his attention to the opposite (north-east) quadrant and note the time when the last traces of the corona disappear. This may be best done in conjunction with (*e*) by an extra observer, who may have his eyes carefully guarded from the brighter corona with the help of a small disc held in the hand and who should pay his undivided attention, at least for the second half of totality, to the north-east quadrant.

(*g*) *Meteorological Observations* :—

(A) *Temperature.*—This is the most important meteorological observation to be made during an eclipse. A thermometer reading at least to half degrees should be hung on a cross

bar away from any building or trees and kept just shaded from the sun. During the progress of the eclipse note the temperature every five minutes. As totality approaches the readings must be taken every minute and special readings should be taken at the commencement and end of totality. The readings then must be continued to be taken every minute for the next quarter of an hour, after which time the interval should be again increased to five minutes. Care should be taken not to be too near the thermometer while taking the readings. Some previous experience in reading the thermometer from a distance in the dark with the help of a lantern will prove of much value. The light of the lantern must on no account fall on the *bulb* of the thermometer.

(B) With a barometer observe if there is any sudden fluctuation of pressure at the moment of totality.

(C) Note any *alteration* in the direction of the wind at the instant of totality.

(D) If provided with a hygrometer, observations may be taken of humidity during the progress of the eclipse.

(*h*) *Shadow-bands.*—Thin parallel lines of shadowy waves flit silently over the landscape just immediately before and after totality. Perhaps at one time eight inches broad and two or three feet apart, at another only one or two inches broad and ten or twelve inches apart, they travel at one time about as fast as a man can run, and at another time with the velocity of an express train. These occur a little before and after totality. They may be best observed on a very large sheet of white cloth stretched on the ground. In each case observe the direction, breadth and distance of these bands and try to count the number of them passing across any one point on the ground in say, ten seconds; the *direction* must be noted by compass.

(*i*) *Effect on Plants, Animals, &c.*—Notice any effect produced on animals and plants during the progress of the eclipse such as stated in paragraph 2.

*General.*—In sending records, great care should be observed in exactly stating the place and time of observations, and full details should be furnished of instruments or the means employed in making the observations. Any further information may be obtained on addressing the undersigned at "Camp Jeur."

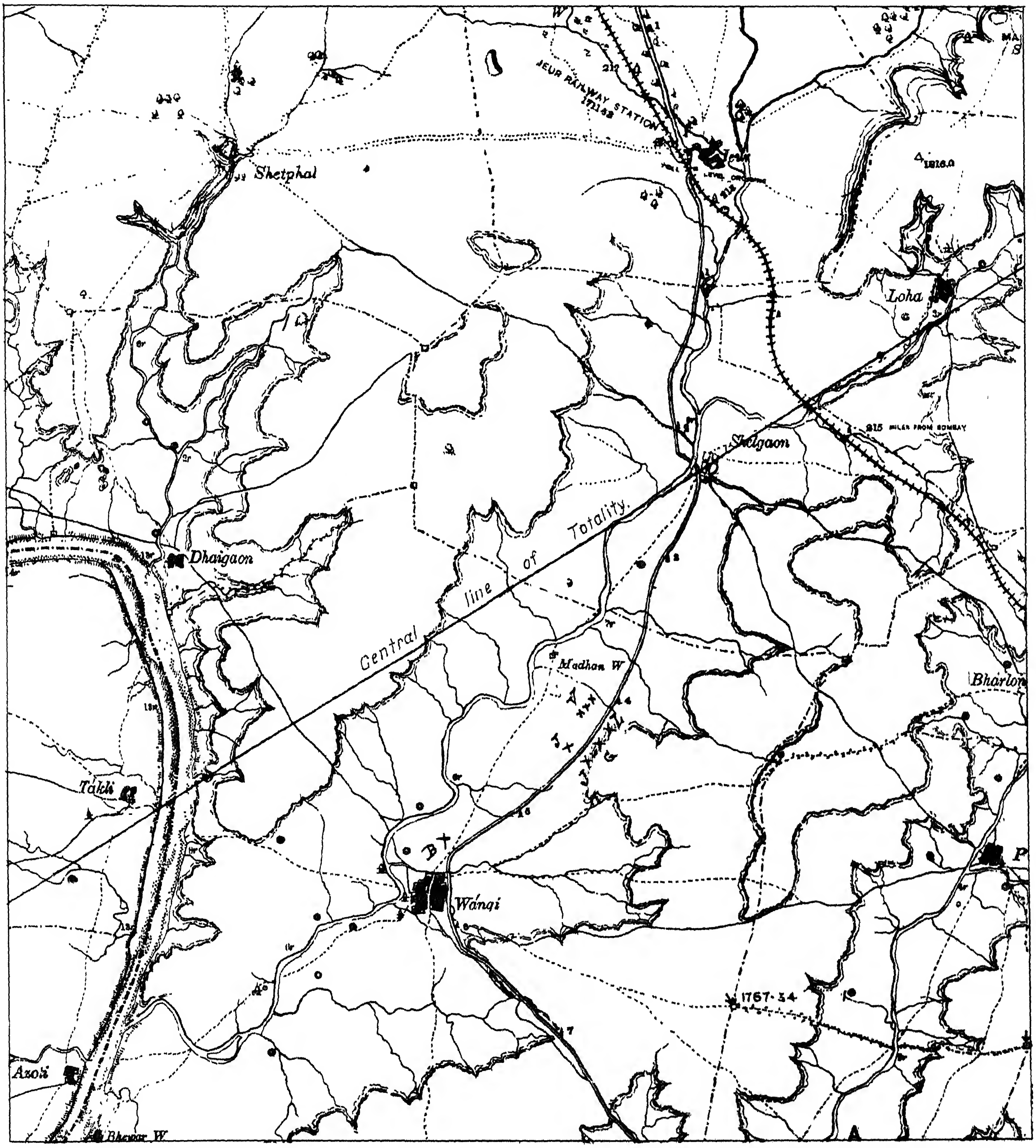
K. D. NAEGAMVALA.

*Maharaja Takhtasingji Observatory*;
*Poona, December* 1897.

# MAP OF THE DISTRICT IN WHICH THE ECLIPSE PARTIES WERE LOCATED

Scale of English Miles

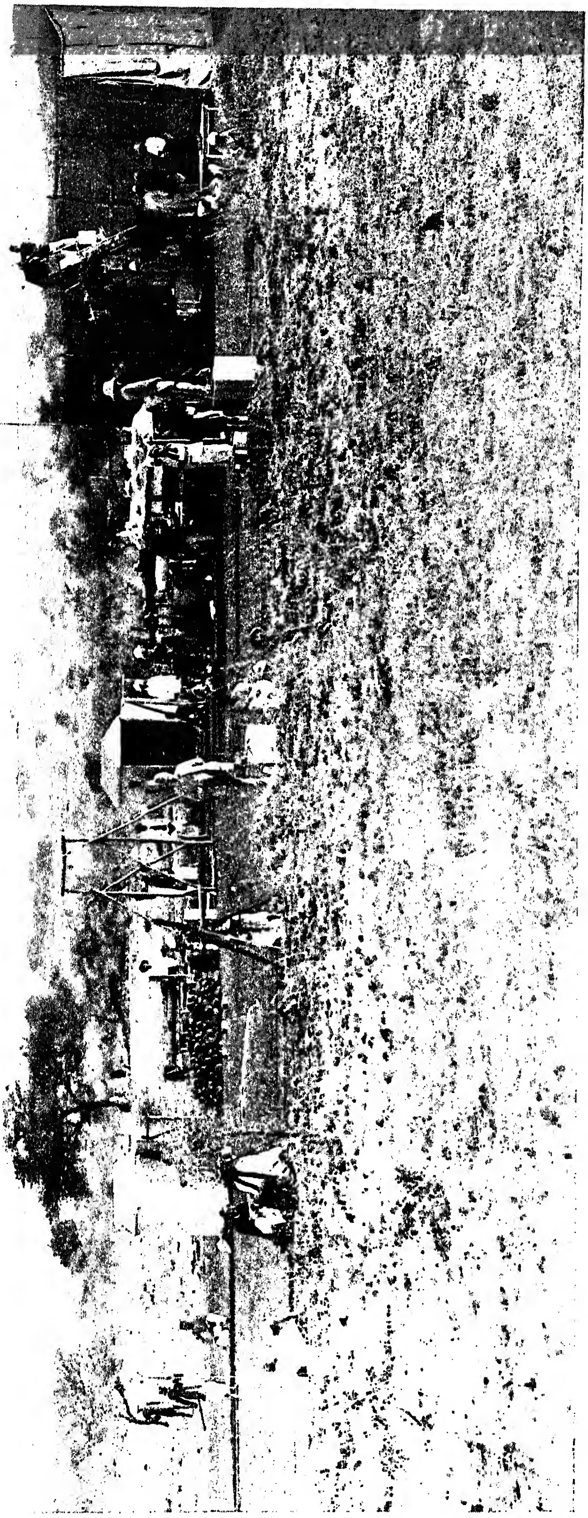
0 1 2 3




*G = Poona Government Party. L = Lick Observatory Party. J = Japanese Camps, V = Volunteers assisting Govt. Party. B = Prof. Burckhalter's Camp.*

*Photozincographed from a printed copy*
*Govt Photozinco. Office, Poona., 1902*

PLATE III.

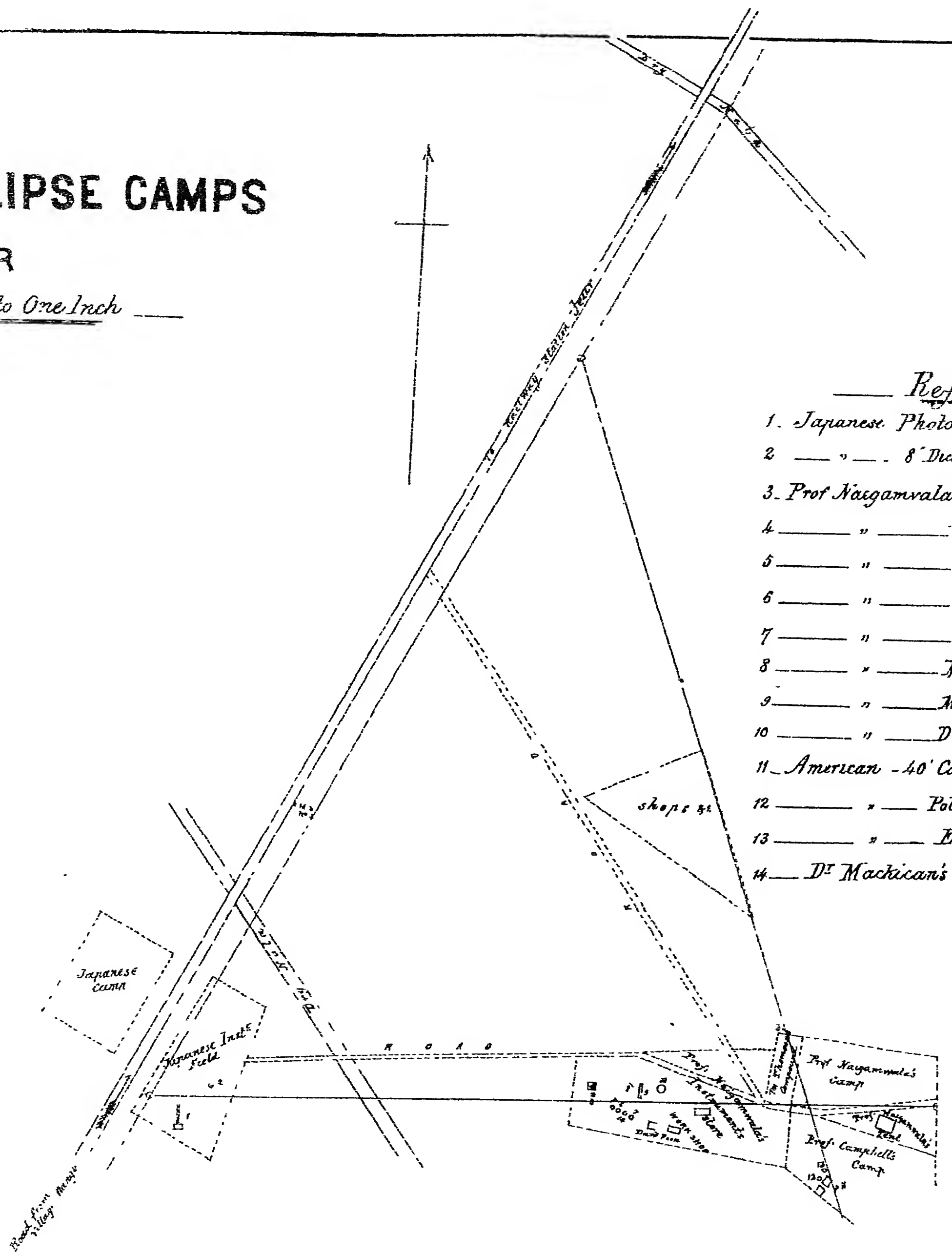


Photograph of Camp.

# SOLAR ECLIPSE CAMPS

## JEUR

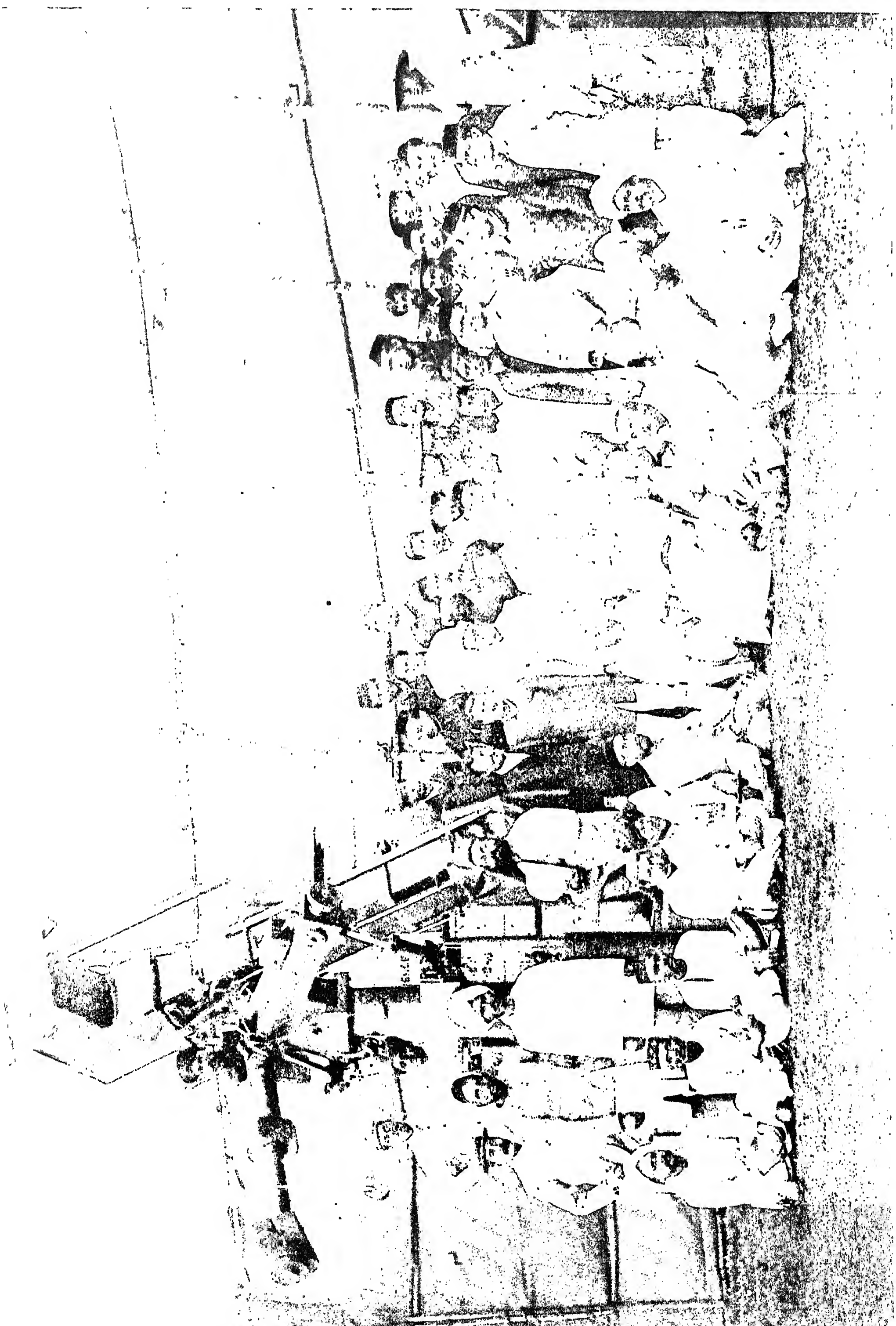
*Scale 360 Feet to One Inch*




### References

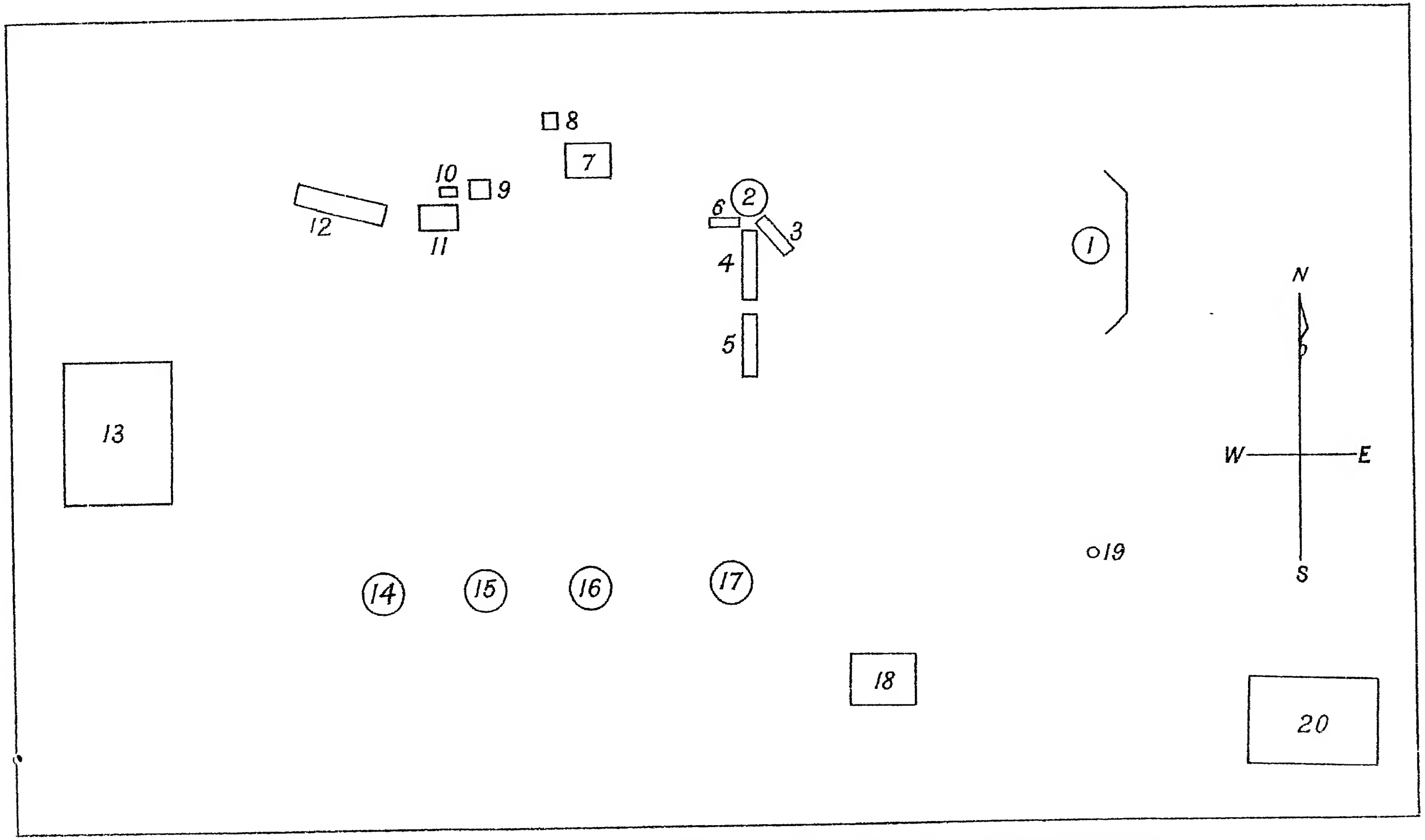
1. Japanese Photo-heliograph 36' Telescope
2. " 8" Dia Doublet
3. Prof Naegamvala's Radiation Thermometer
4. " Meteorological Observatory
5. " Father Haan's Telescope
6. " Mr Kishi's
7. " Mr Sanga's Integrating Spectroscope
8. " Mr Hudson's Instrument
9. " Mr Woodrow's Instrument
10. " Dr Thomson's Instrument
11. American 40' Camera Object glass at the top
12. " Polar axis with 6 Instruments.
13. " Equatorial mounting with 2 Spectroscope
14. Dr Mackican's Instrument.

*Reduced to Scale from a Tracing*
*Govᵗ Photozinco Office Poona, 1902*



The Observing Party.

Plate IV

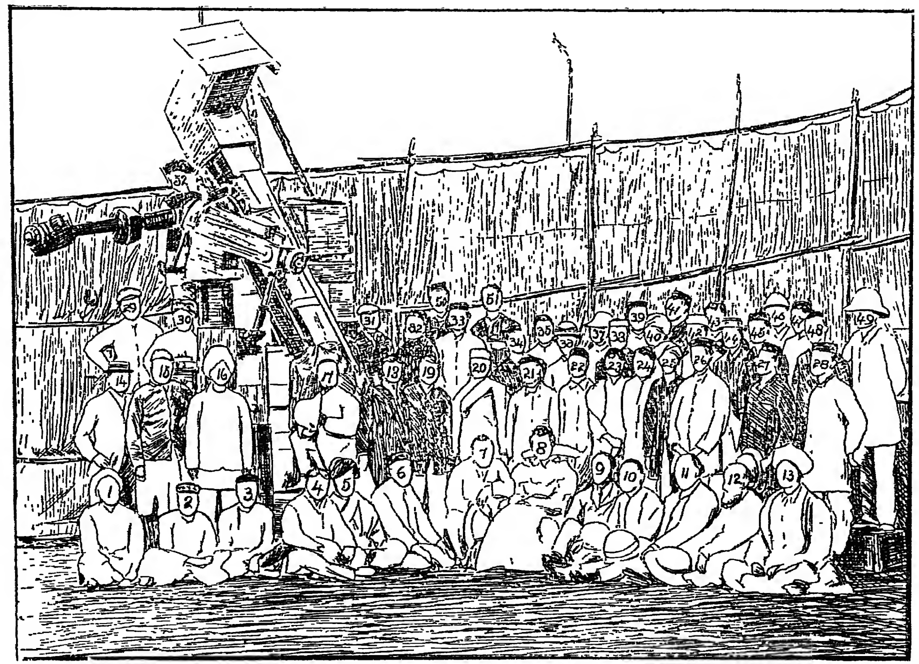



1 6" Prismatic Camera
2 Siderostat.
3 Single spar prism.
4 8" Image lens.
5 Slit spectroscope.
6 Two prism spar.
7 Seconds Clock
8 4" Coronagraph.
9 Well for clock weight.
10 Clock of Cœlostat
11 Cœlostat.
12 6" Coronagraph
13 Meteorological hut.
14 Slitless analysing spectroscope.
15 3" Telescope.
16 Prismatic telescope.
17 Integrating spectrograph.
18 Dark room.
19 Directors seat.
20 Workshop.

PLAN OF CAMP SHOWING THE DISPOSITION OF THE INSTRUMENTS.

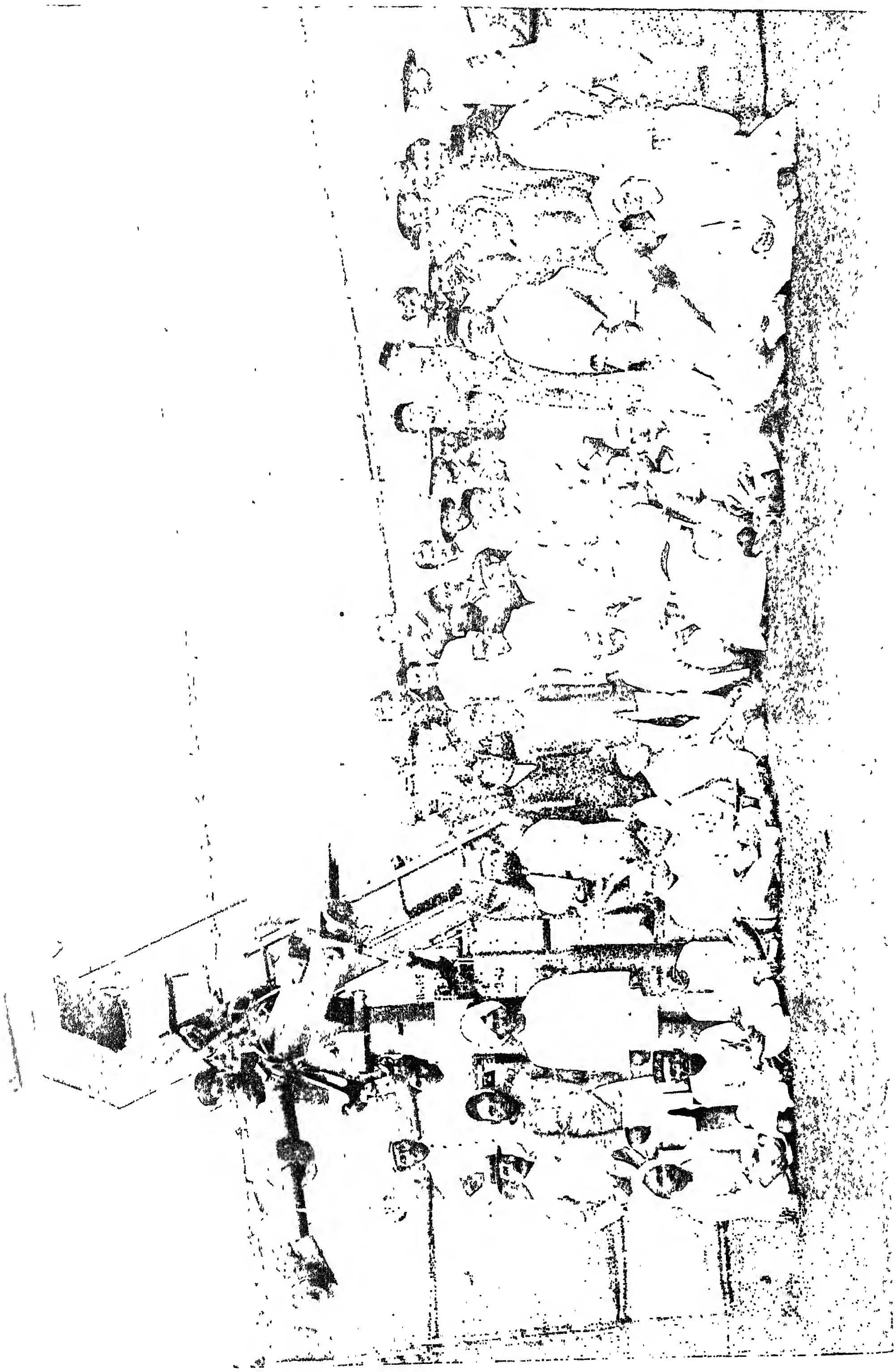
Govt Photozinco Office Poona 1902

*Key to the photograph of the observing party.*



1. Mr. S. G. Paranjpe.
2. Carpenter Narayan.
3. Carpenter Dhansing.
4. Dr. P. P. Mulla, L. M. & S.
5. Mr. G. B. Rishi, L. C. E.
6. Mr. D. D. Sanga.
7. Professor A. W. Thomson, D. Sc.
8. Mrs. Thomson.
9. Professor G. M. Woodrow, F. L. S.
10. Professor K. D. Naegamvala, M. A.
11. Rev. Principal Dr. D. Mackichan, M. A. D. D., LL. D.
12. Rev. Professor F. X. Hann, S. J.
13. Professor R. N. Apte, M. A., LL. B.
14. Mr. A. G. Hudson.
15. Mr. Syedlal Syedchand.
16. Syed Mahomed Syed Yakub.
17. Mr. S. D. Writer.
18. Mr. P. T. Pavri, B. Sc.
19. Mr. B. K. Bana, B. Sc.
20. Mr. N. V. Deokule.
21. Mr. K. D. Sanga.
22. Mr. F. S. Bharucha.
23. Mr. K. M. Ghosh.
24. Mr. K. B. Senroy.
25. Mr. D. G. Dani, B, Sc.
26. Mr. T. J. Pitre.
27. Mr. J. D. Dubash.
28. Mr. A. B. Vaidya.
29. Mr. P. De Souza.
30. Mr. V. K. Kanitkar, L. C. E.
31. Mr. P. K. Naegamvala.
32. Mr. B. E. Vacha, B. Sc.
33. Mr. T. B. Vakil.
34. Mr. B. A. Wadia.
35. Mr. D. R. Sataravala B. A.
36. Mr. H. J. Unvala, B. Sc.
37. Mr. H. D. Mistri.
38. Mr. F. X. Vaz.
39. Mr. P. S. Joshi.
40. Mr. B. S. Barve.
41. Mr. D. D. Kapadia, M. A., B. Sc.
42. Mr. V. N. Godbole.
43. Mr. D. Bal.
44. Mr. J. Nazereth.
45. Mr. R. D. Naegamvala.
46. Mr. A. Gonsalves.
47. Mr. K. Banerji.
48. Mr. M. S. Murzban.
49. Mr. H. A. Lilamvala.
50. Mr. M. R. Vakil, B. A.
51. Mr. D. K. Kulkarni.
52. Attendant Govind Jotiba.

PLATE VI



The Observing Party.

Six-inch prismatic camera.

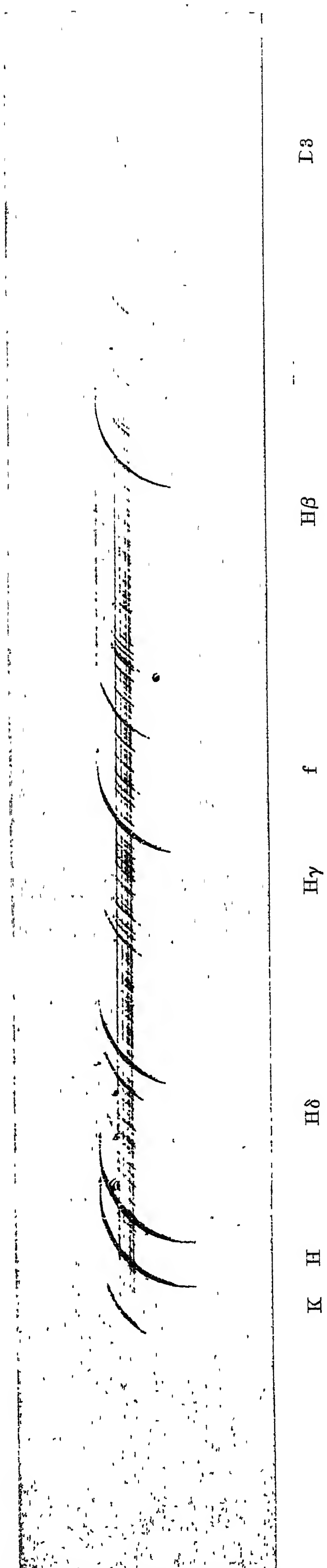



Fig. 1. Spectrum of the Flash at second contact.

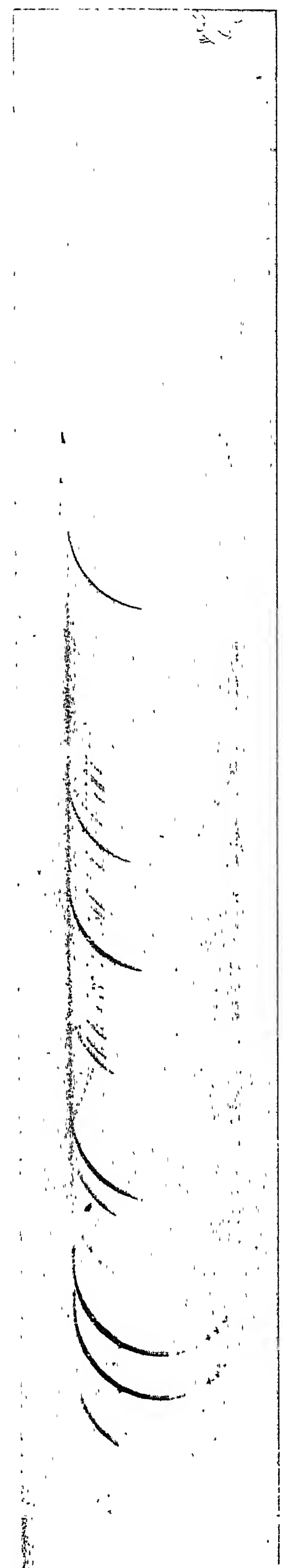


Fig. 2. Spectrum taken five seconds after second contact.

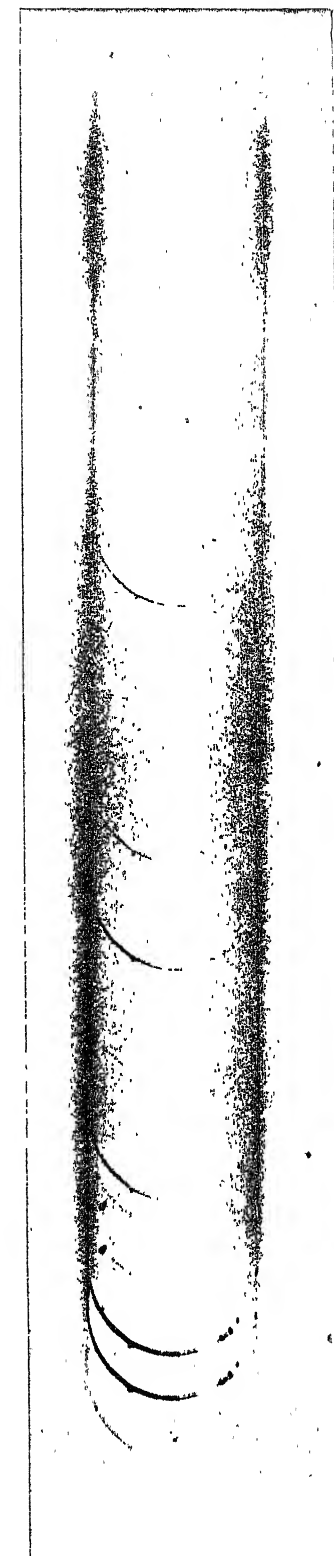
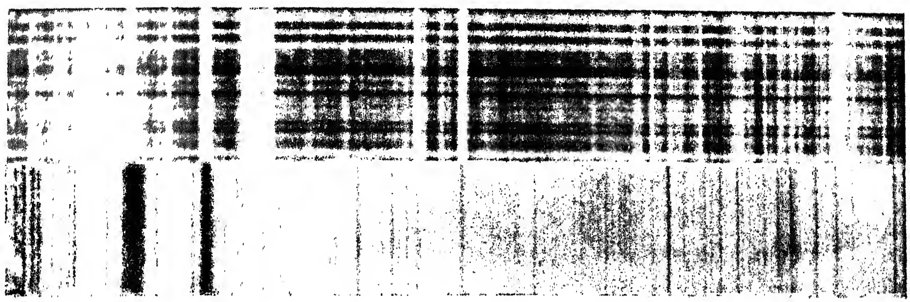


Fig. 3. Spectrum taken fifteen seconds after totality.

(The bright arcs are shown dark on the plate).

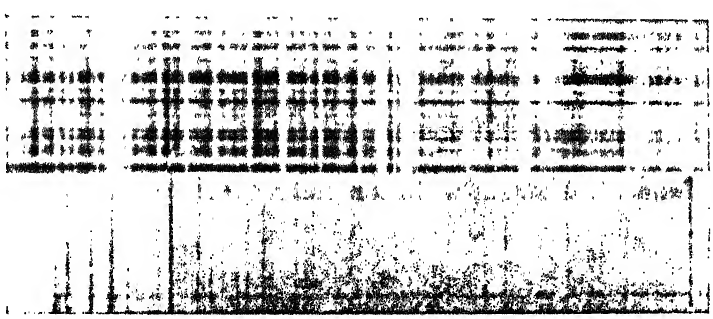
PLATE X.



Flash spectrum.

Fraunhofer spectrum.

*K* *H* *H* $H_\gamma$

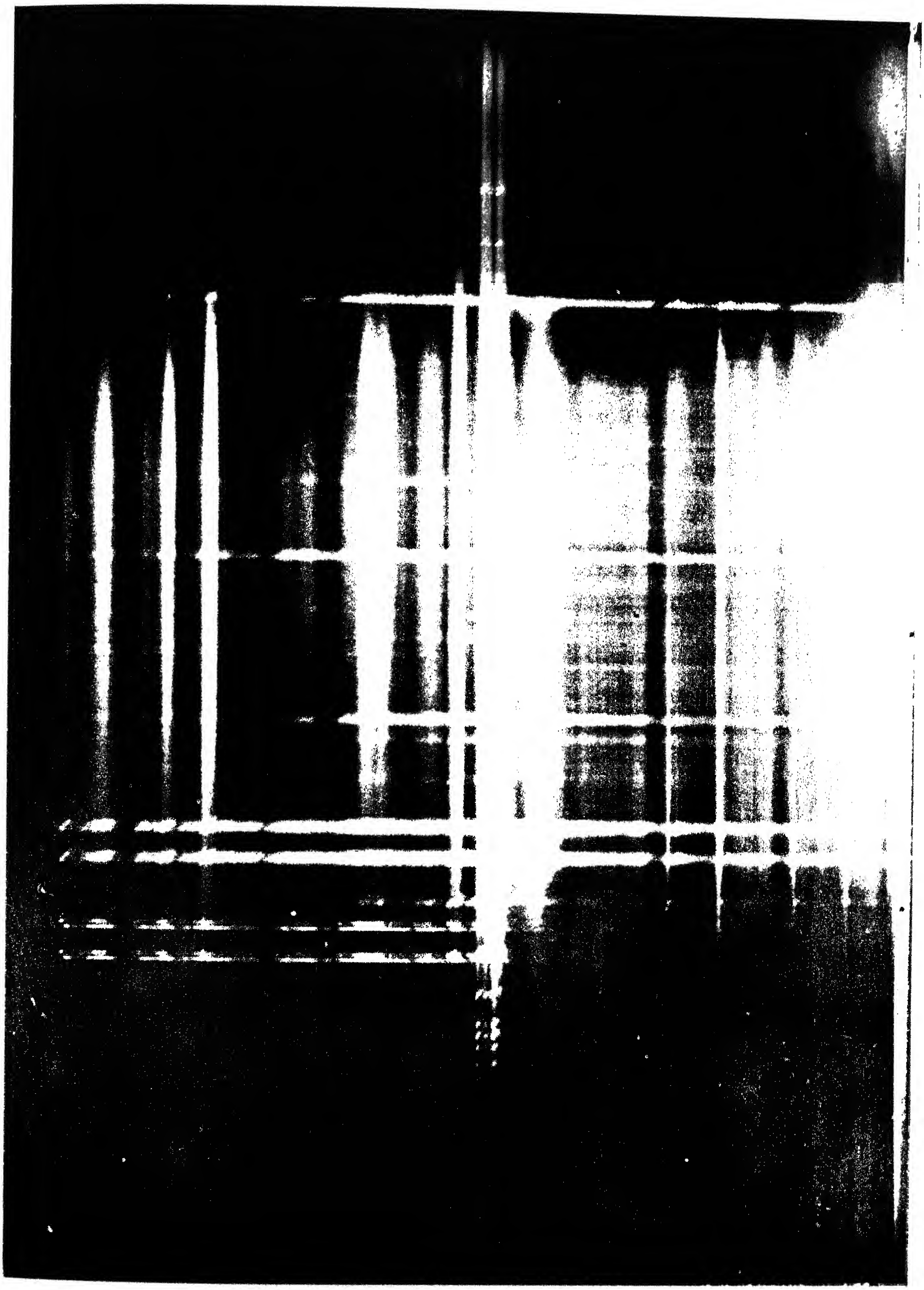


Flash spectrum.

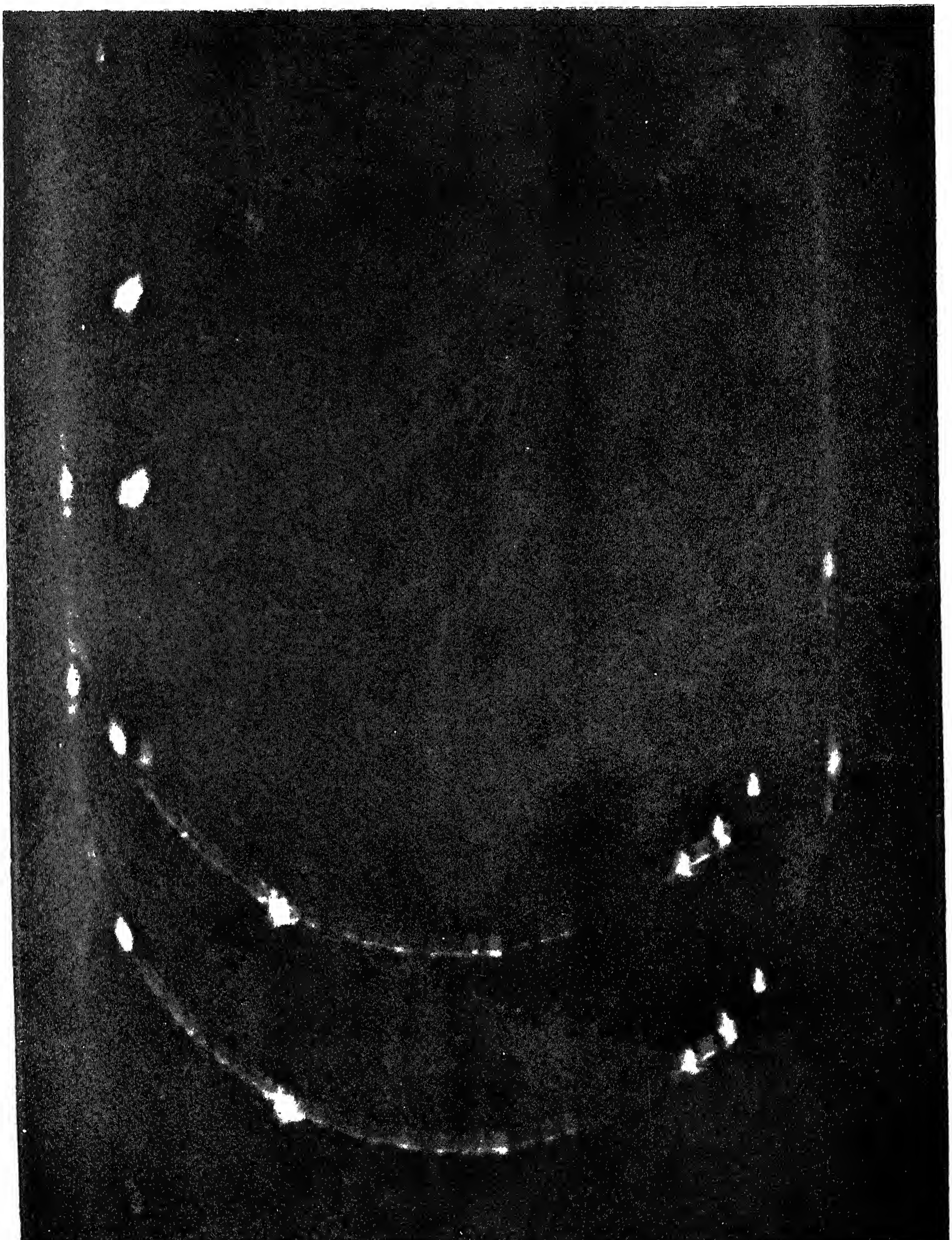
Fraunhofer spectrum.

*H*

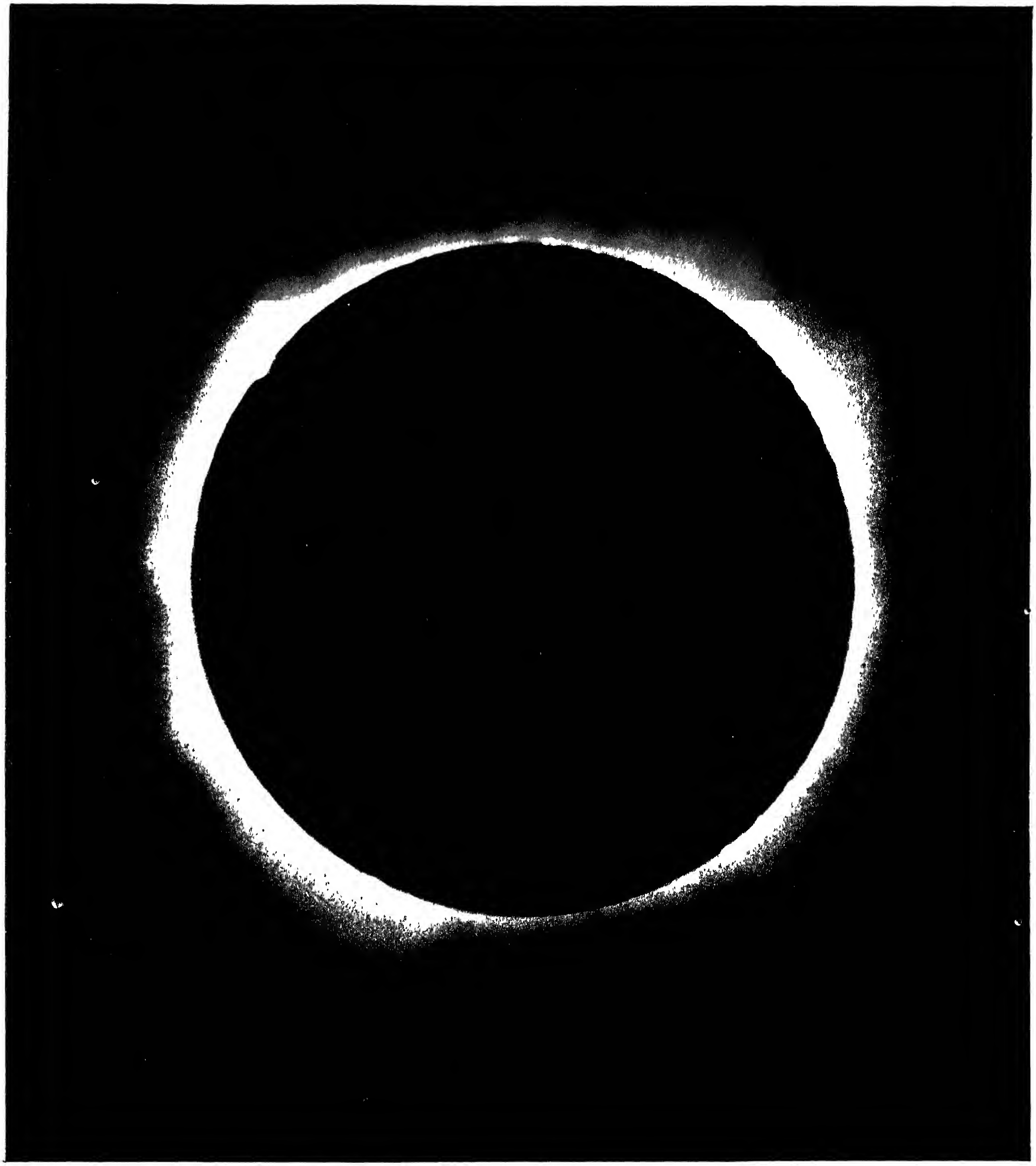
[illegible] compared with the Fraunhofer spectrum.



Spectrum of the Flash at third contact (running plate).

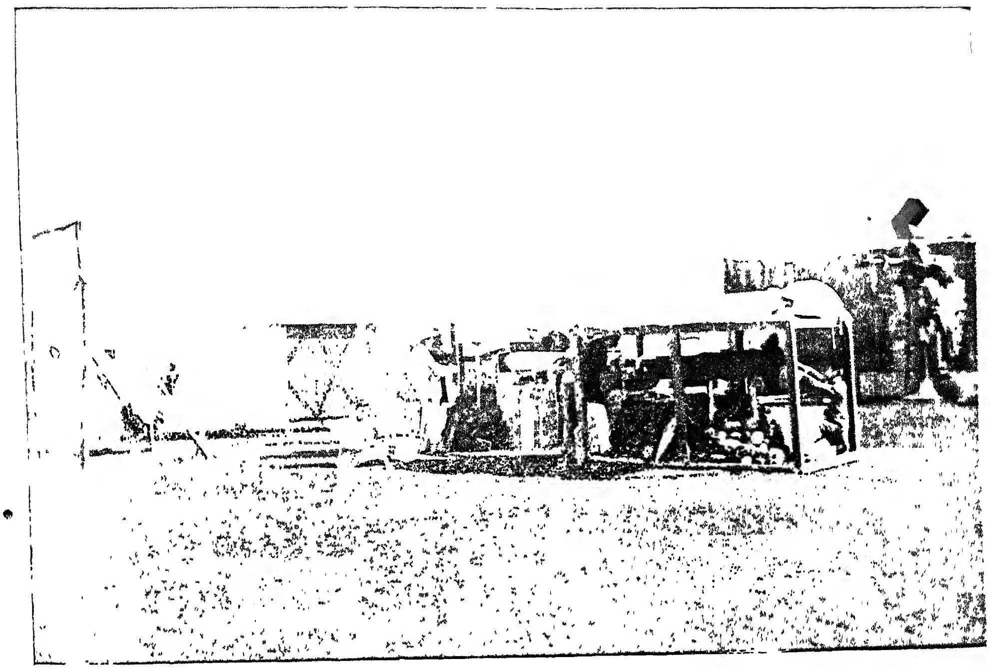


Prominences photographed in H and K radiations by the prismatic camera.
(Campare with Plate XIII.)



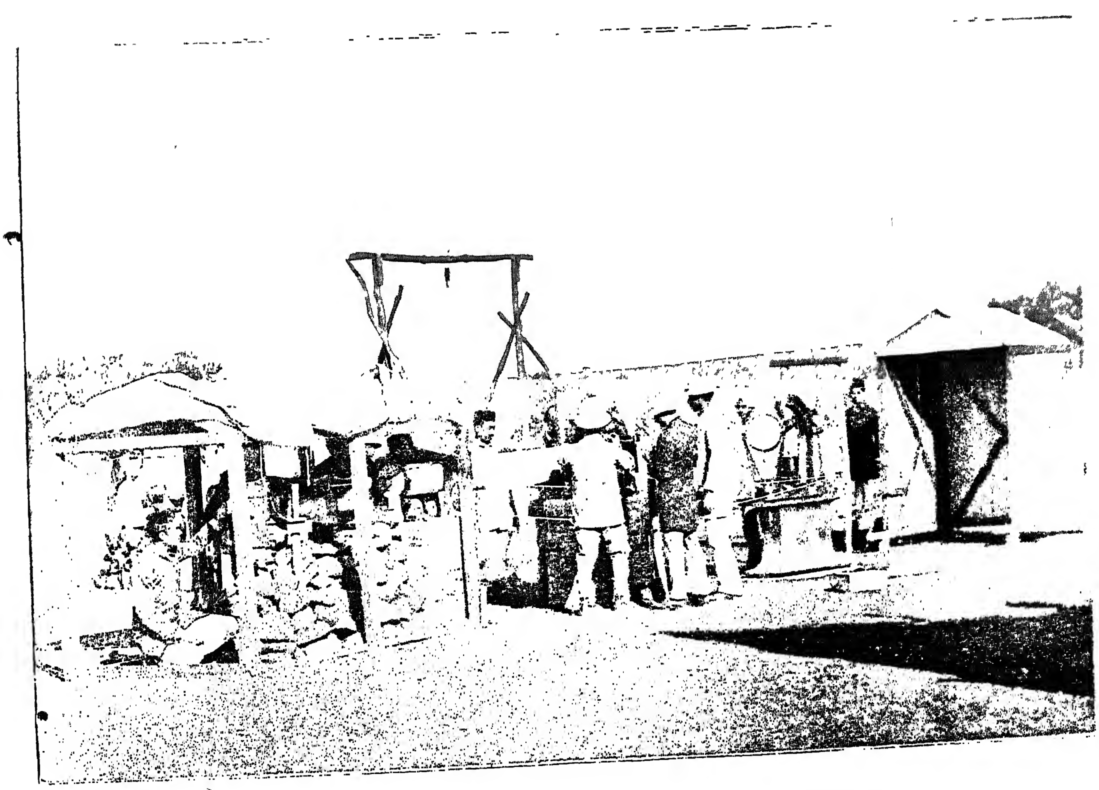
Direct photograph of the Eclipse showing prominences. (Copeland.)

*Fig. 1.*

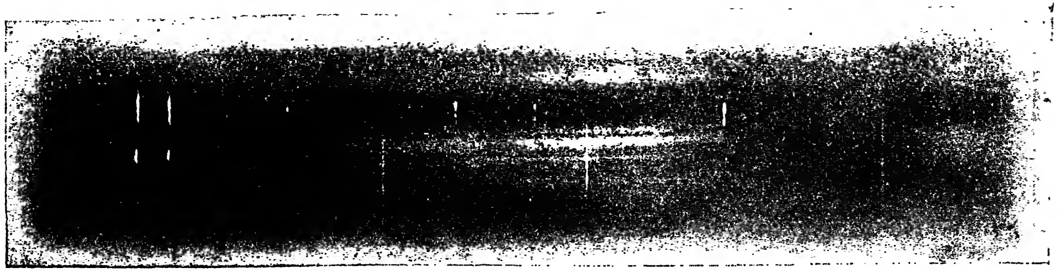


Siderostat and slit spectrograph with two-prism ultraviolet prismatic camera.

*Fig. 2.*

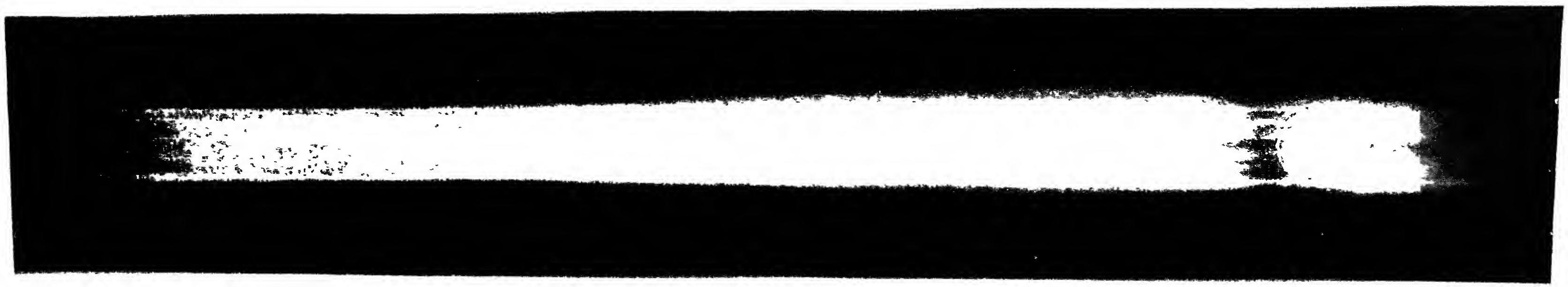


Siderostat and slit spectrograph with one-prism ultraviolet r



K H Hδ Cor. Hγ f Cor Hβ Cor.

Fig. 1. Spectrum of the corona with the slit spectrograph.



Cor. Cor K H Cor

Fig. 2. Spectrum of the corona with the two prism ultra-violet prismatic camera.

Fig 1. Integrating spectrograph.

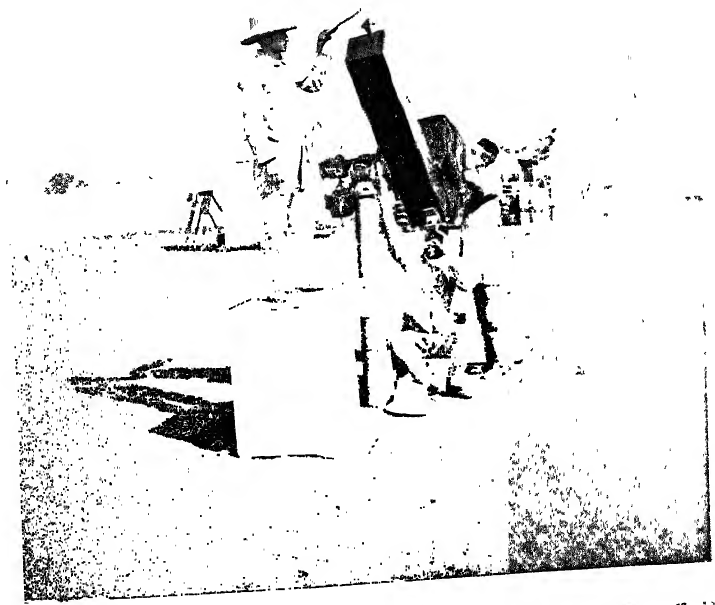
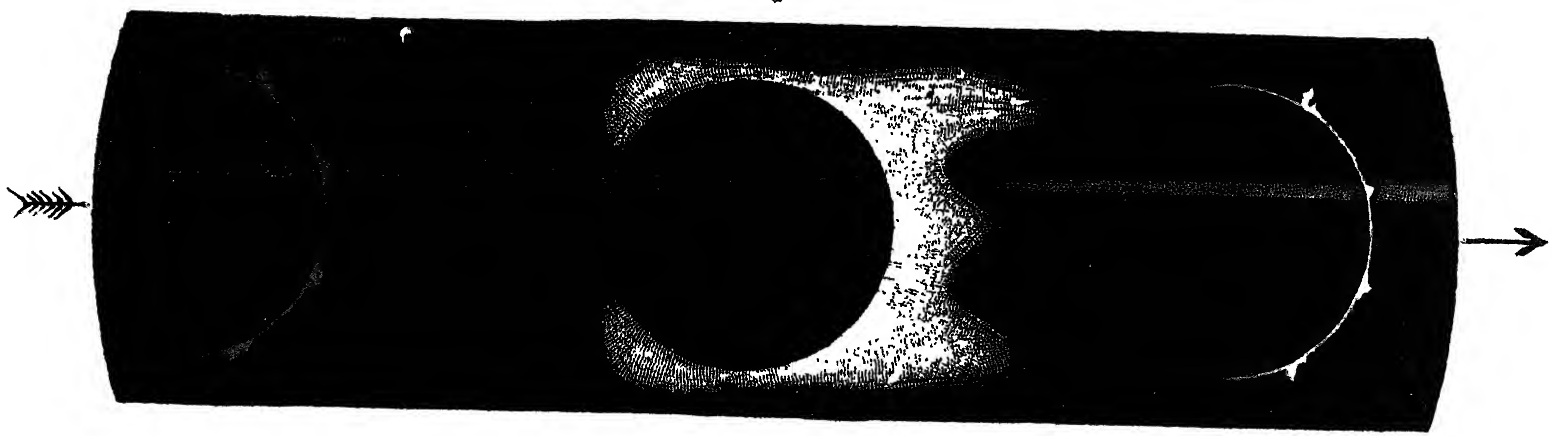


Fig 2. Another view of the integrating spectrograph.

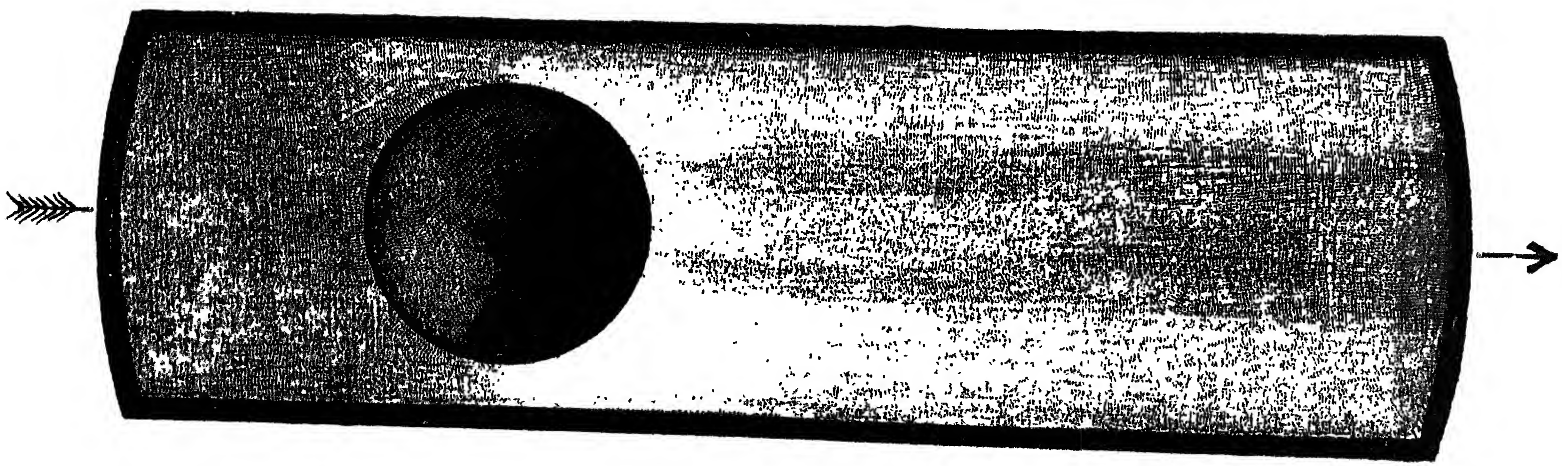
CORONA SPECTRUM AS OBSERVED WITH THE SLITLESS ANALYSING SPECTROSCOPE.

Fig 1



5 seconds after the beginning of Totality

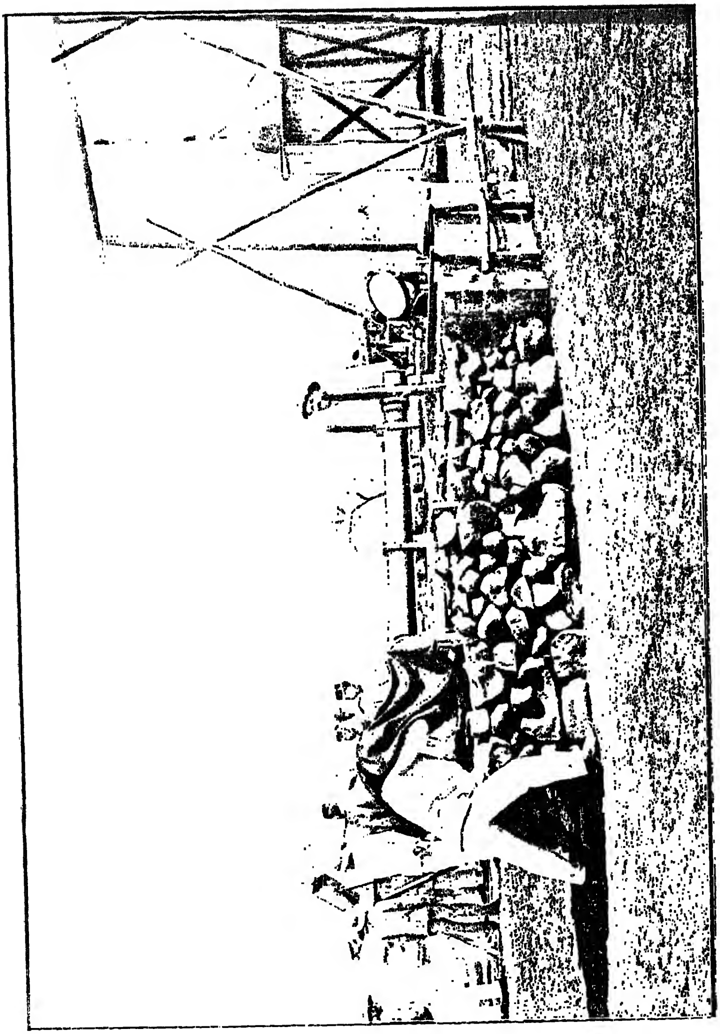
Fig 2



40 seconds before the end of Totality

Litho: Govt. Photozinco. Office. Poona 1902.

PLATE XVIII.



Cœlostat and coronograph.

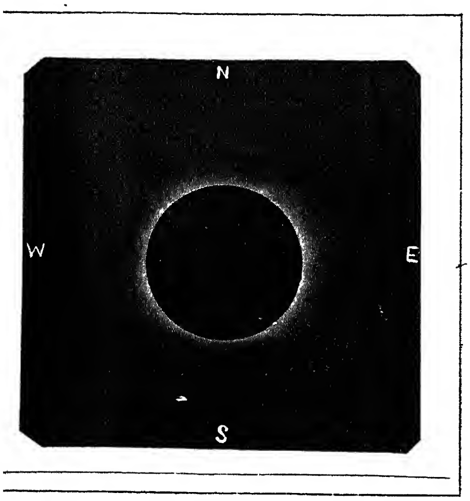



Fig. 1.

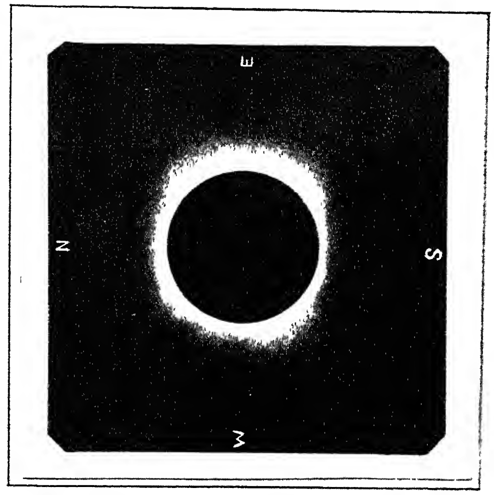



Fig. 2.

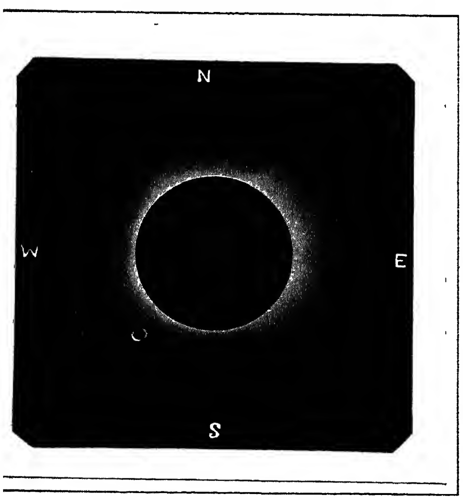



Fig. 3.

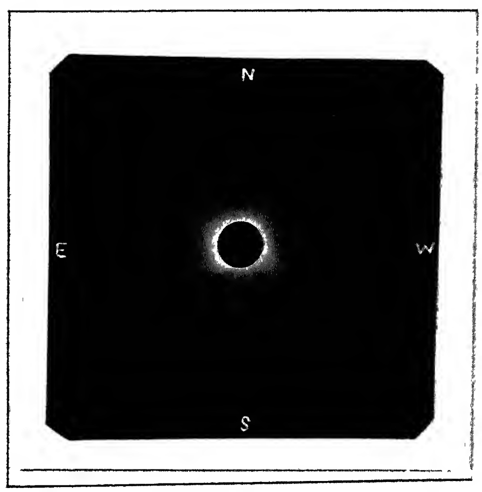


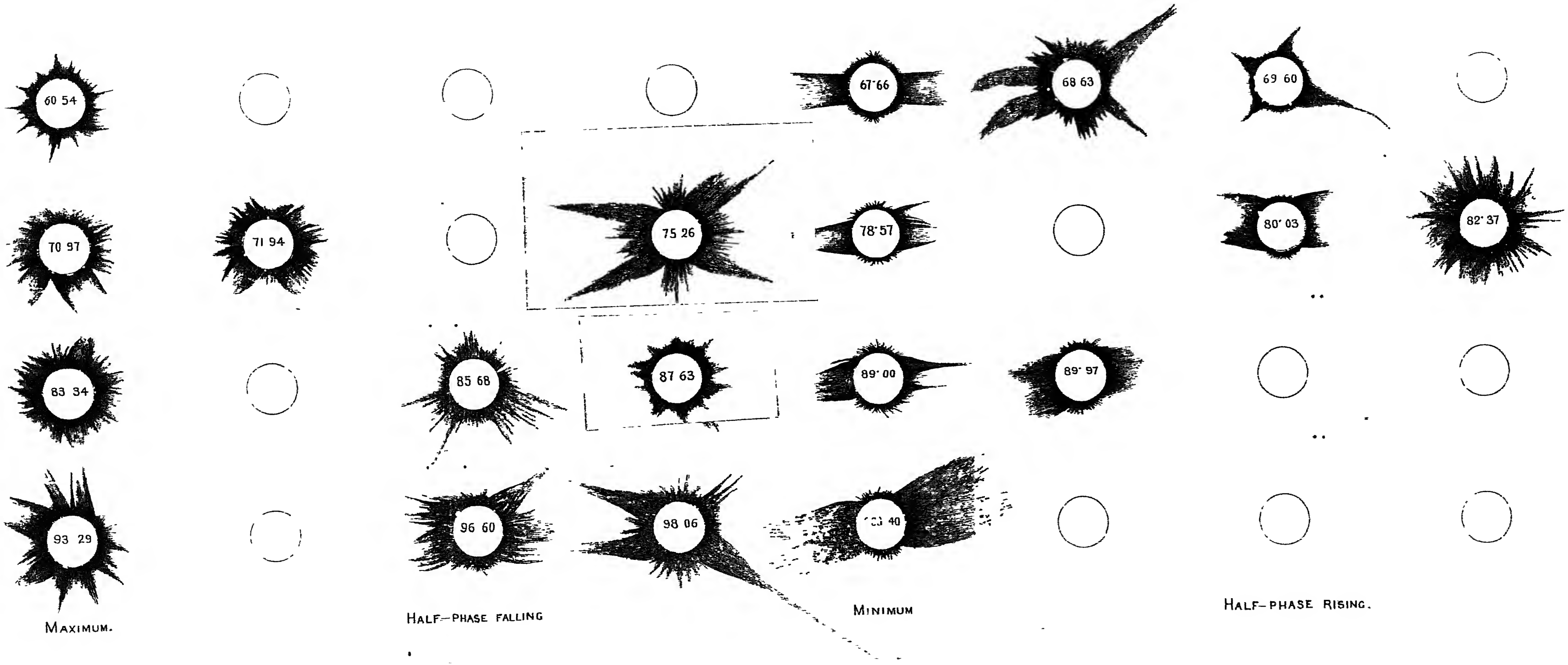

Fig. 4.

TOTAL ECLIPSE OF THE SUN, 22ND JANUARY 1898.

PHOTOGRAPHED AT JEUR.

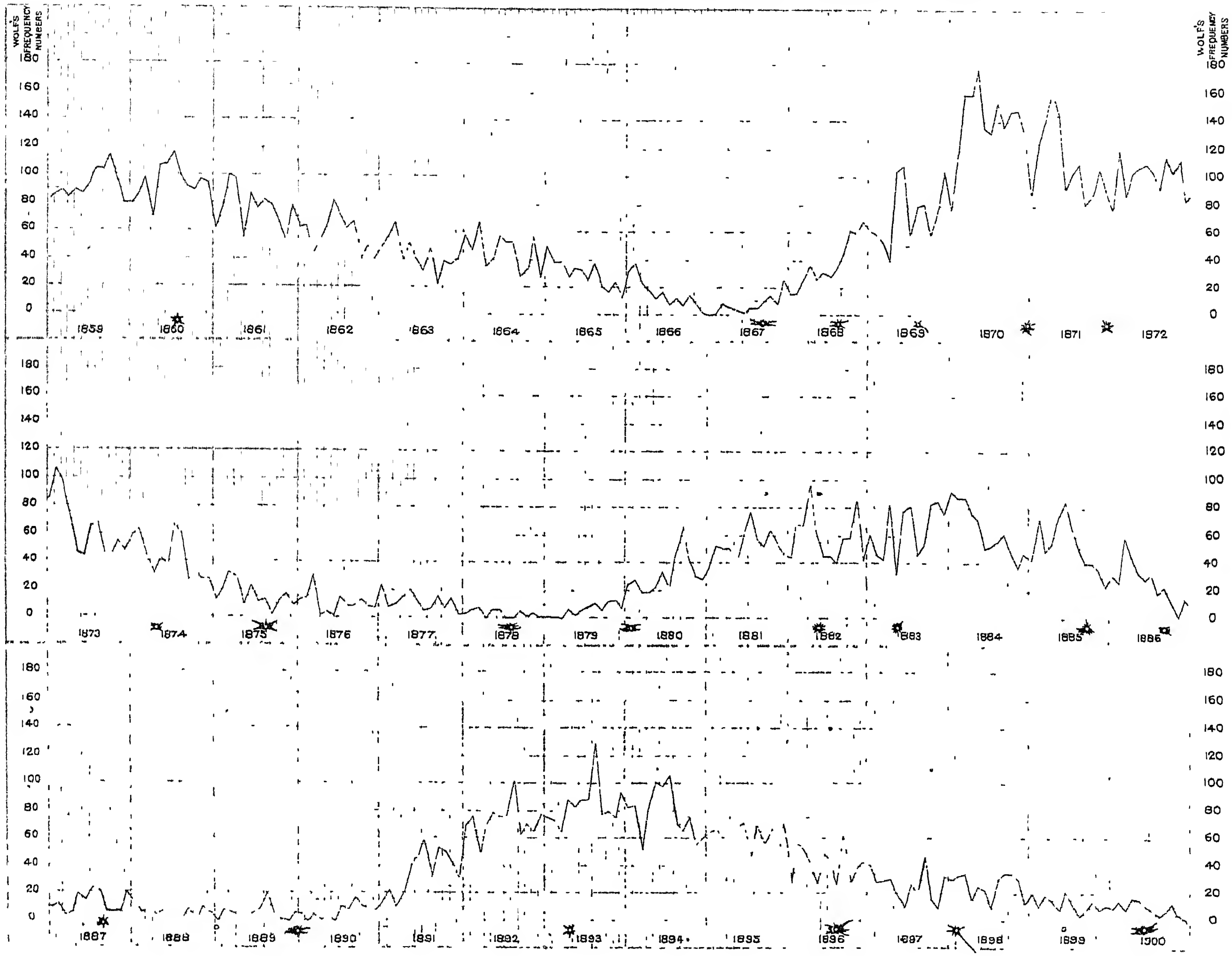
Drawn & Litho. Photozinco. Office, Poona [illegible]

Plate XX




Total Solar Eclipses since 1860 arranged in sun spot cycles.

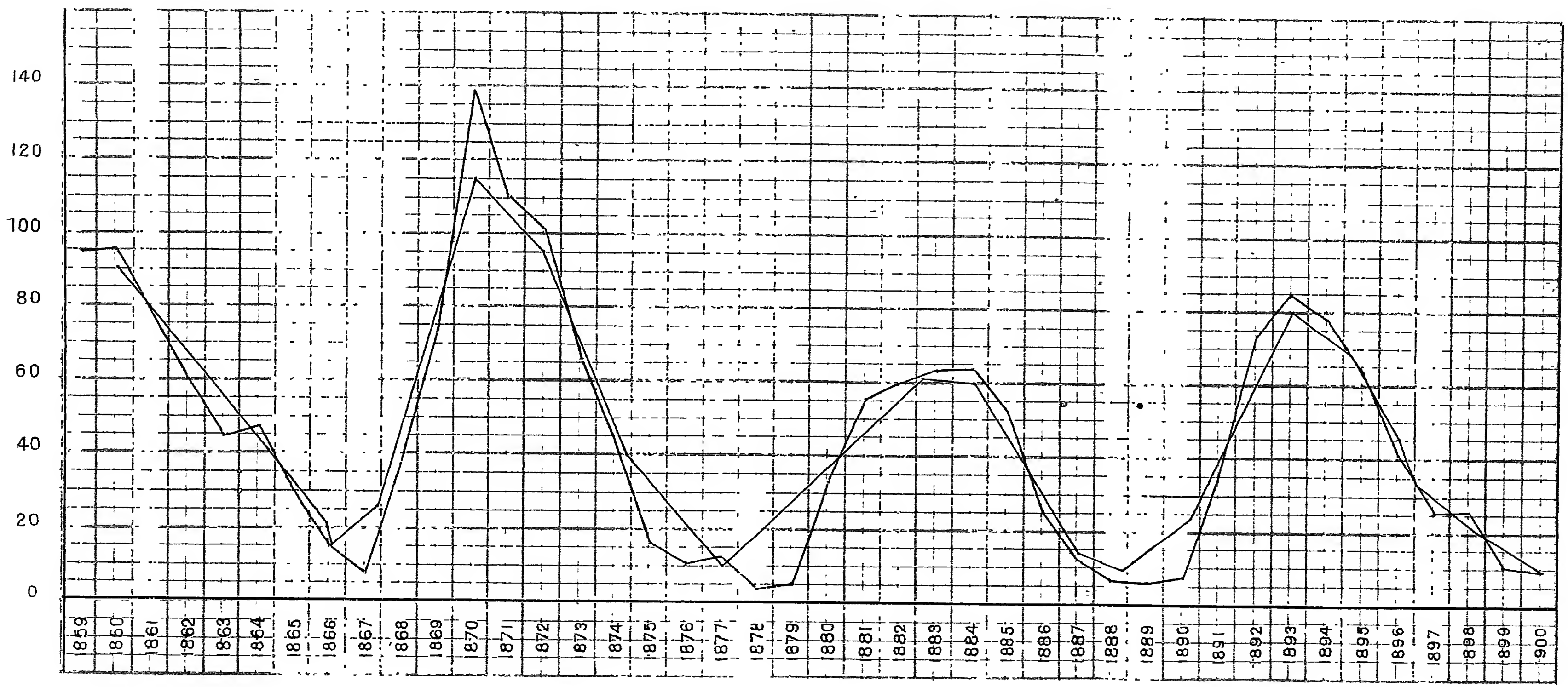
CURVE OF MONTHLY RELATIVE SUN-SPOT FREQUENCY FROM 1859 TO 1900 WITH DATES OF TOTAL SOLAR ECLIPSES




Drawn and Litho Govt Photozinco Office - Poona, 1902

Plate XXII.

# CURVE OF MEAN ANNUAL SUN-SPOT FREQUENCY 1859-1900.

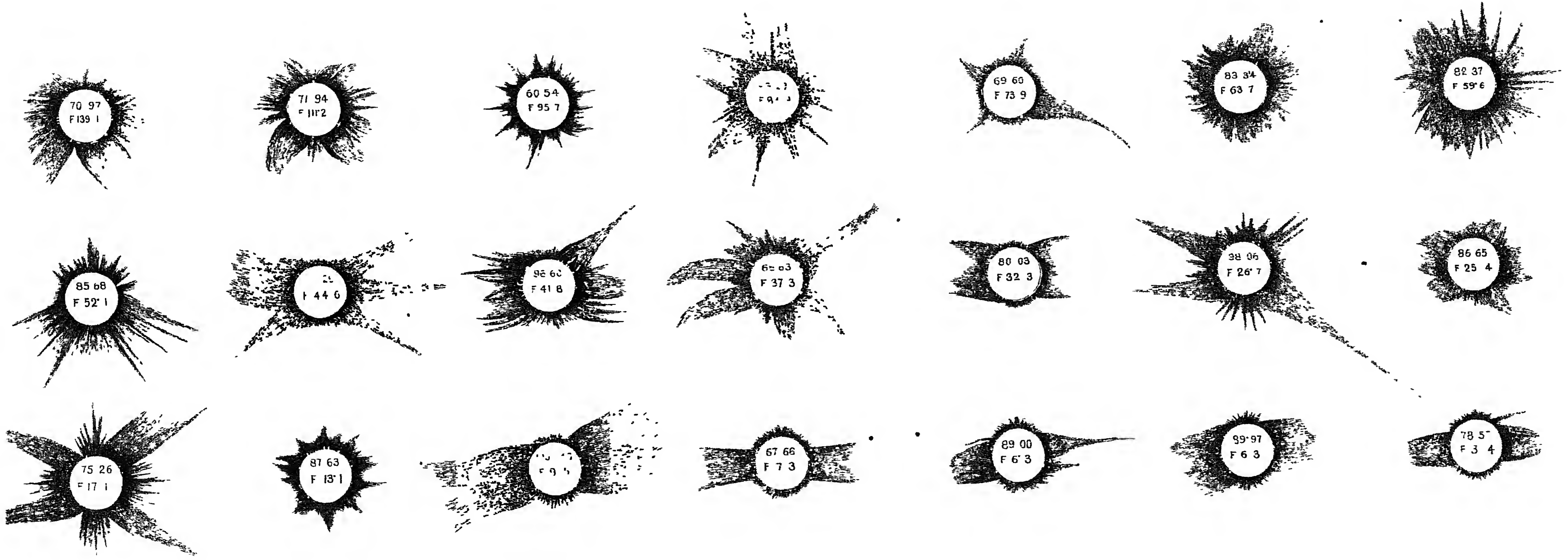



RED:– UNSMOOTHED CURVE OF MEAN ANNUAL SUN-SPOT FREQUENCY.

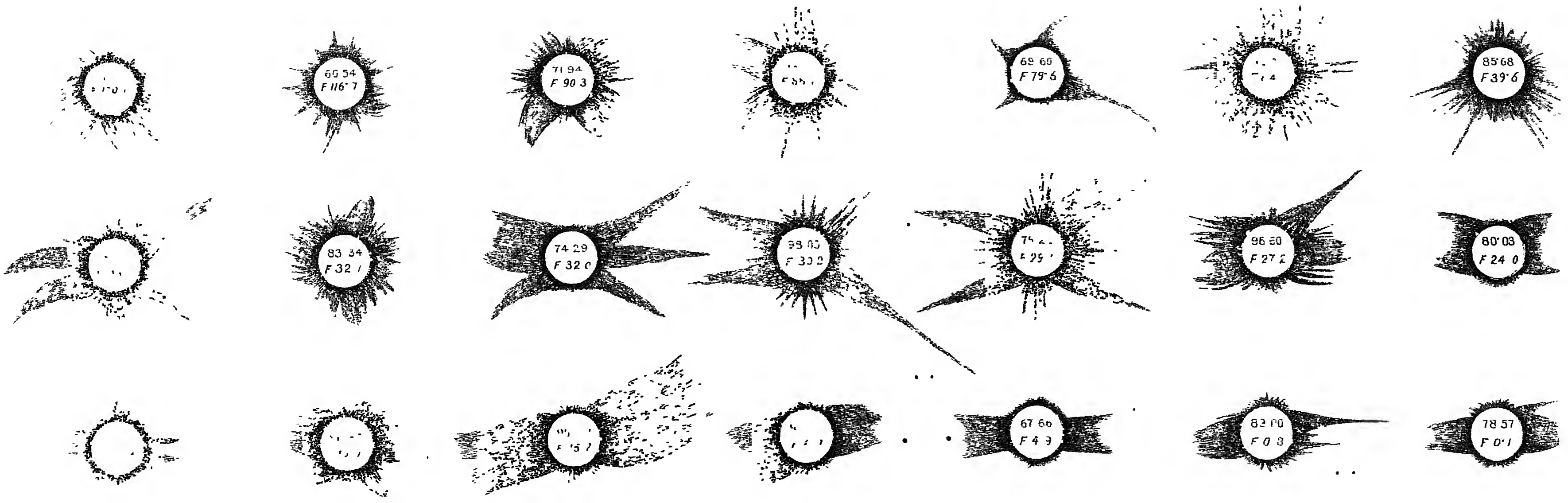
BLACK:– PARTIALLY SMOOTHED CURVE OF THE SAME.

Drawn & Litho Govt Photozinco Office, Poona 1902

Plate XXIII

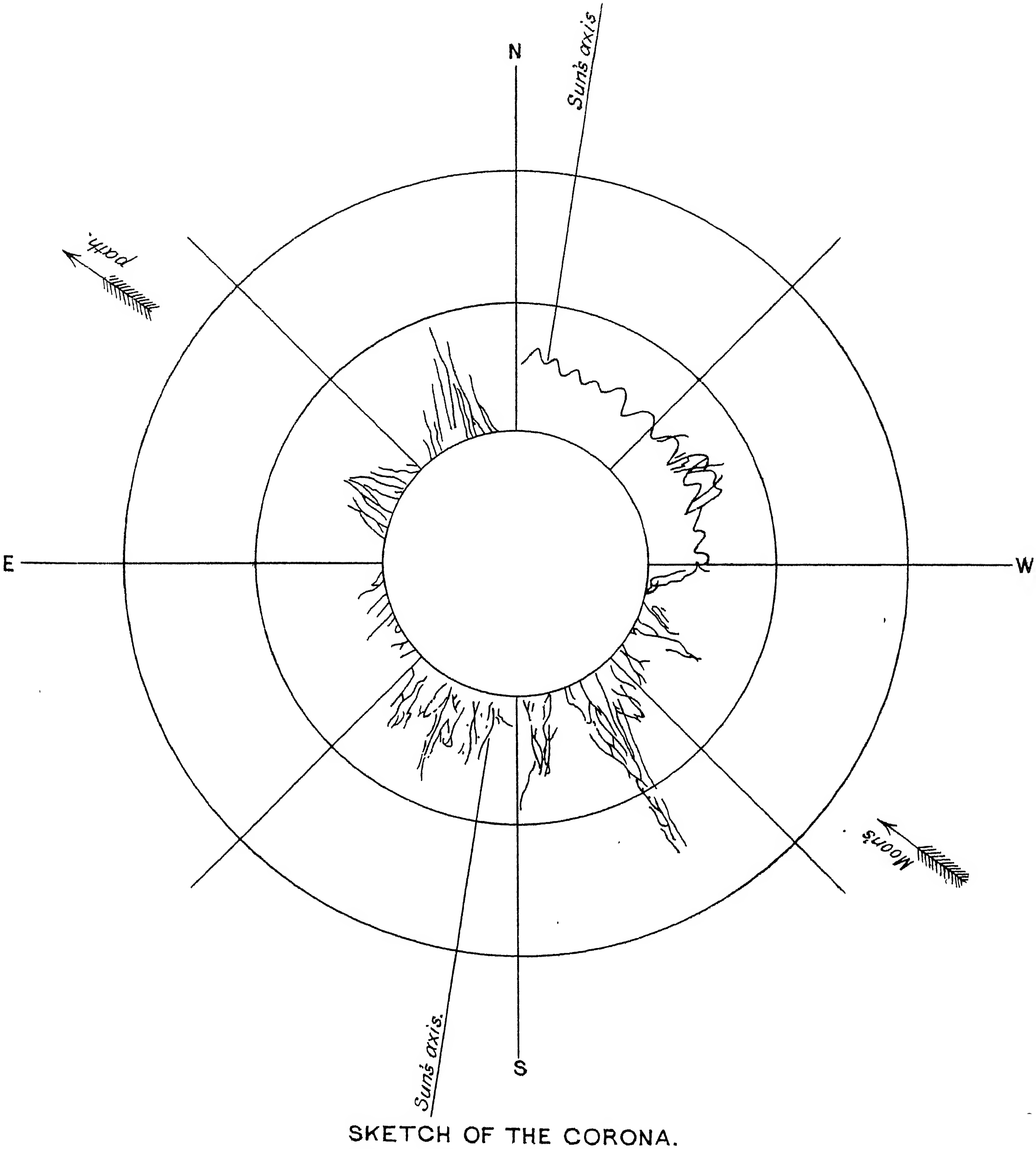



Total Solar Eclipses arranged in descending order of mean annual spot frequency.




TOTAL SOLAR ECLIPSES SINCE 1860 ARRANGED IN DESCENDING ORDER OF MONTHLY SPOT FREQUENCY

Plate XXV.

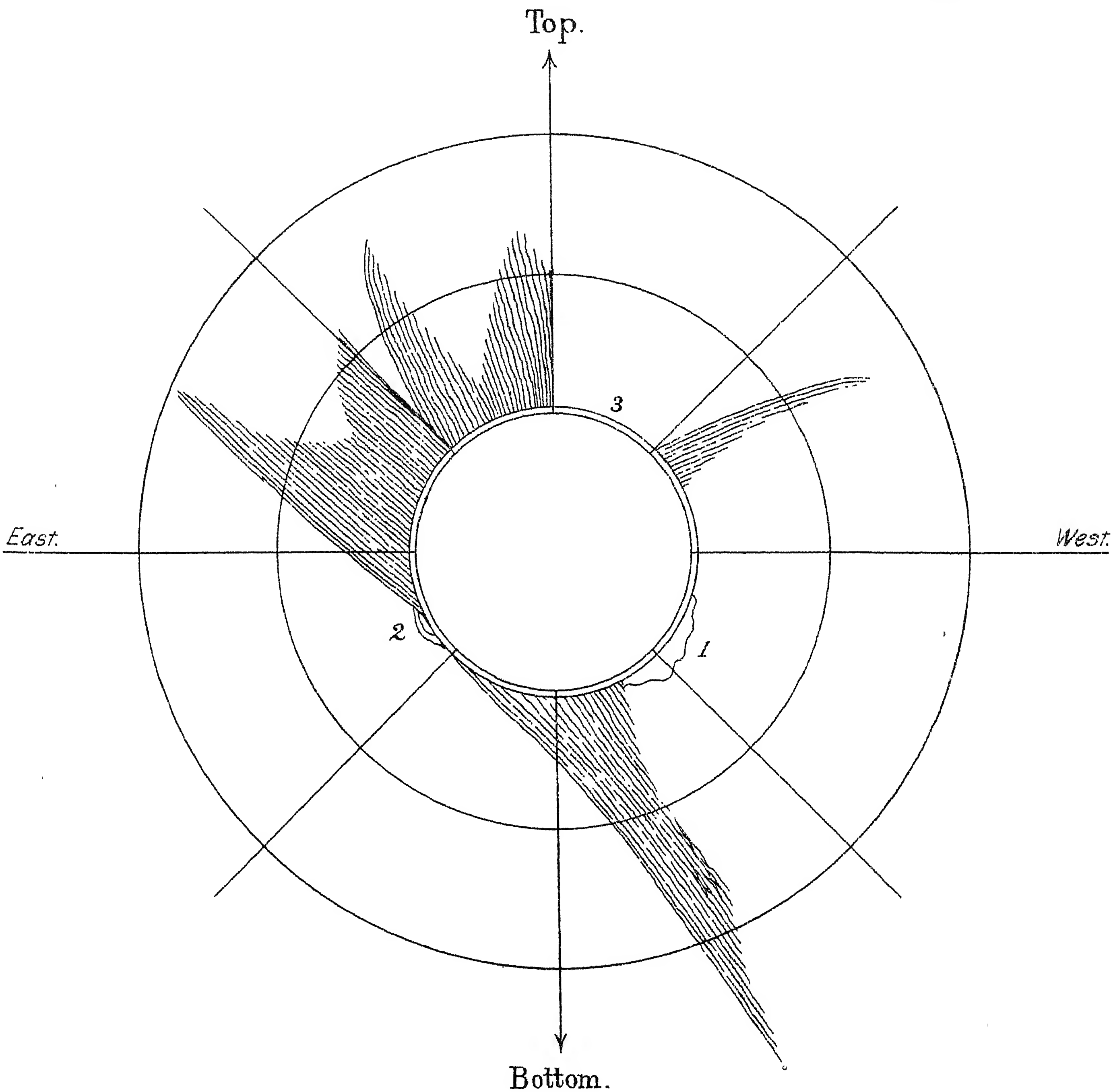



SKETCH OF THE CORONA.

*Drawn by Mr. H. G. Kadne from N. to S. E, arc of 135,°*
*by Mr. R. Yadav from S.E. to W, arc of 135,°*
*and by Mr H. F. Beale from W. to N, arc of 90,°*

Gov<sup></sup>t Photozinco, Office Poona 1902.

Plate XXVI.

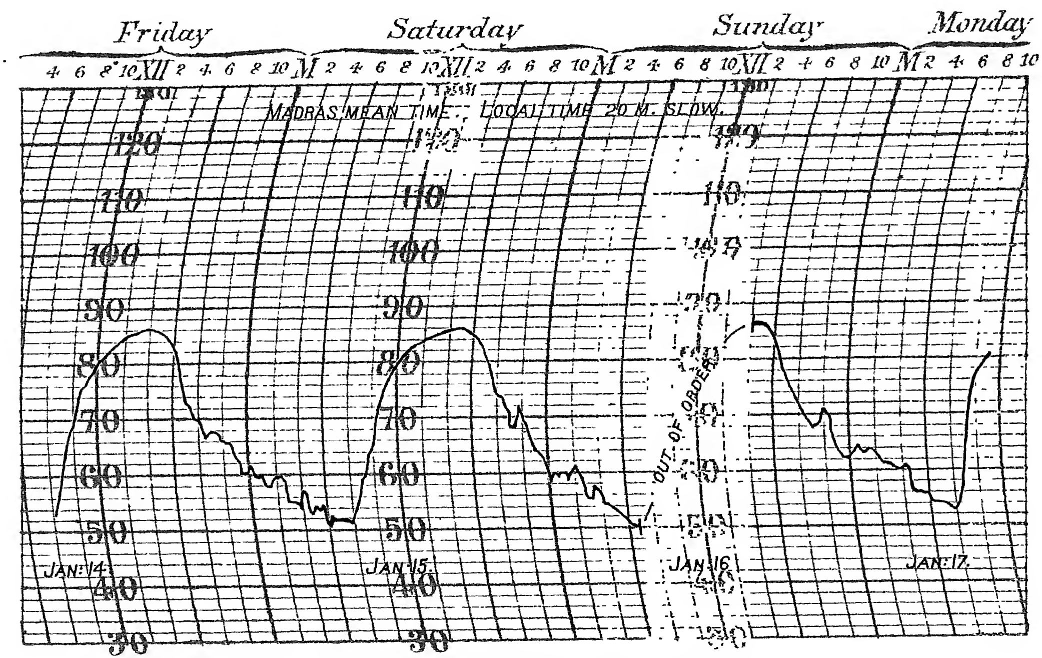



1 Red Mass.
2 Red Flame.
3 Rim of Light.

SKETCH OF THE CORONA MADE BY THE REV. A. ABBOTT.

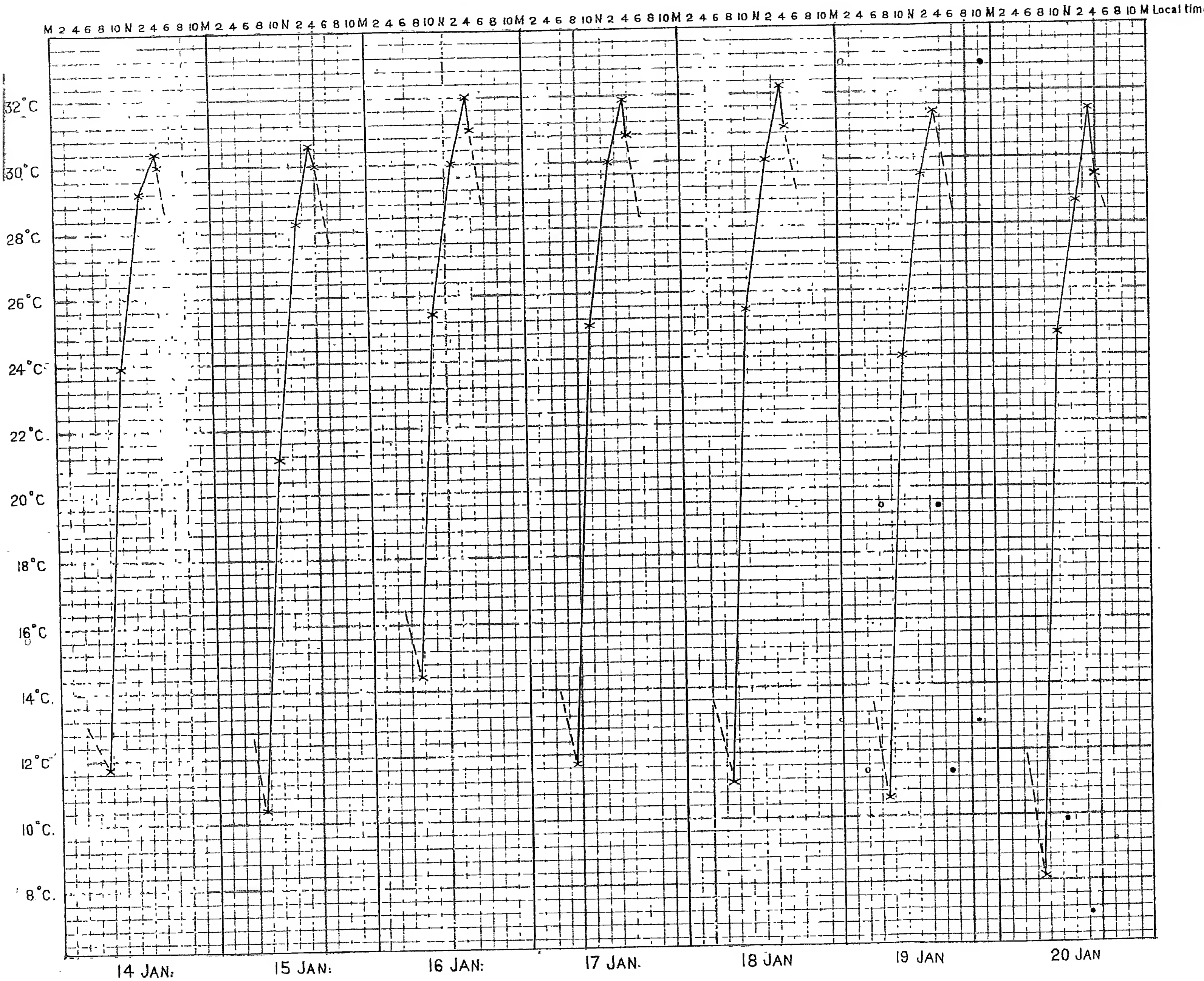
Govt Photozinco. Office Poona 1902.

DAILY VARIATION OF TEMPERATURE AT JEUR.




Drawn & Litho Govt Photozinco Office, Poona, 1902.

Plate XXVIII.




DAY VARIATION OF TEMPERATURE.

Govt Photozinco Office Poona 1902

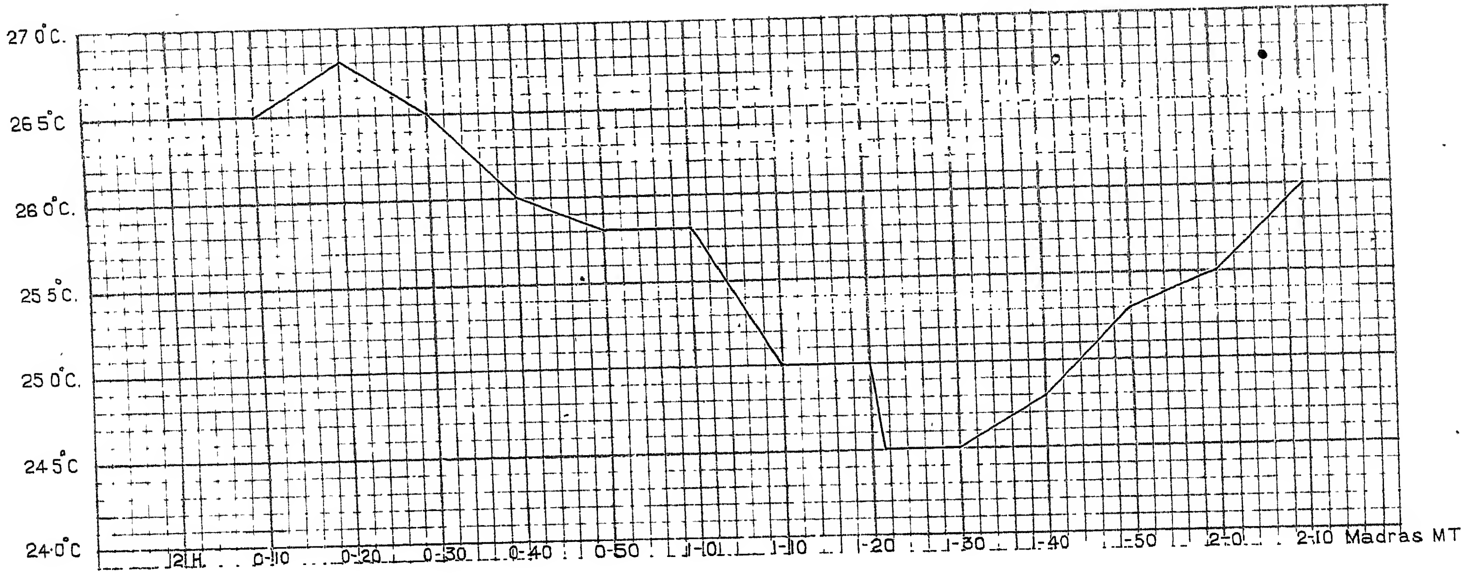



Fig 1.

VARIATION OF TEMPERATURE DURING THE PROGRESS OF THE ECLIPSE.

Totality 1-20 to 1-22 p m. Madras M.T.

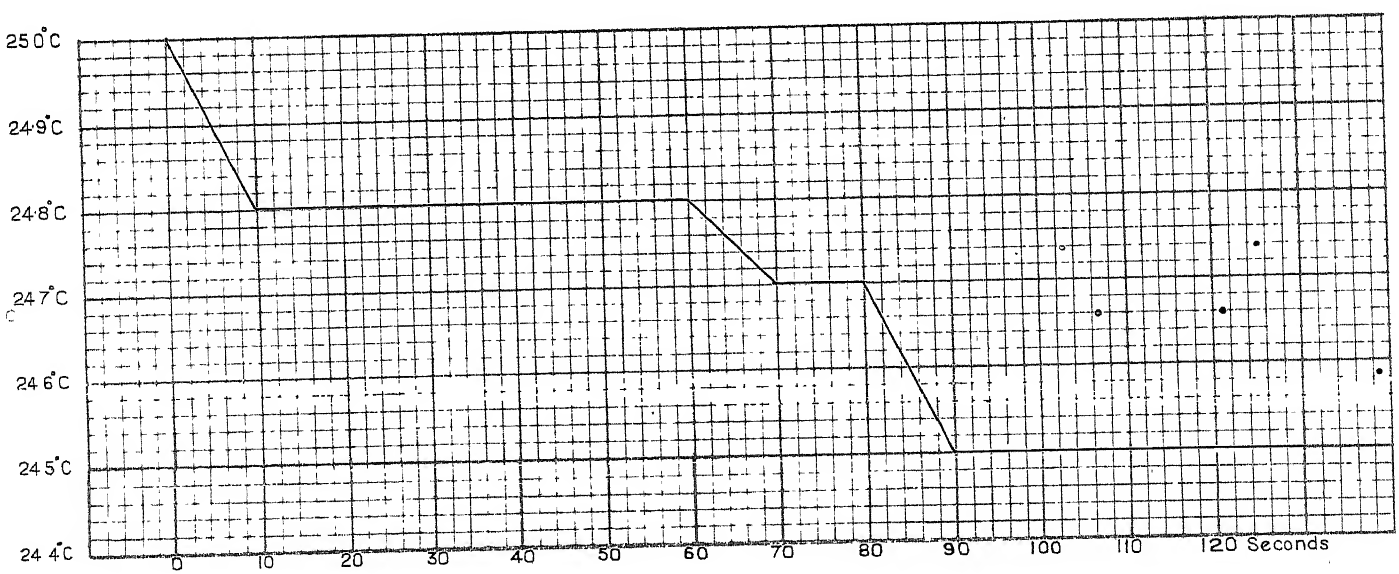
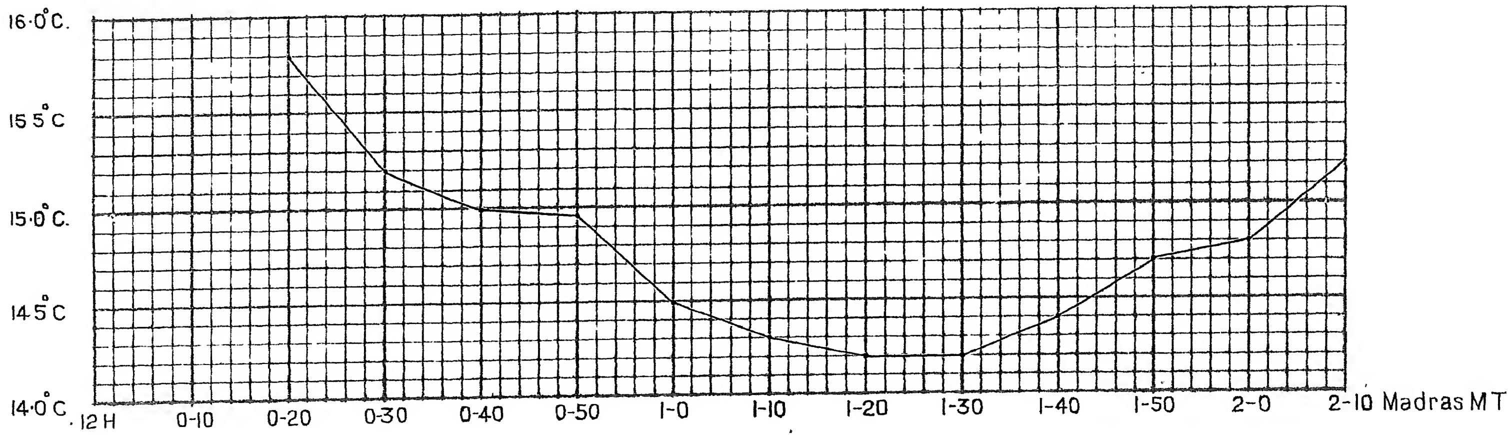



Fig 2.

VARIATION OF TEMPERATURE DURING TOTALITY.

Govt Photozinco Office Poona 1902

Plate XXX.




VARIATION OF WET-BULB THERMOMETER DURING THE PROGRESS OF THE ECLIPSE

Govt Photozinco Office Poona, 1902